SURGERY OF THE SYMPATHETIC NERVOUS SYSTEM

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BY

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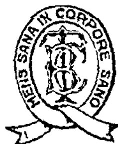
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PREFACE

We have written this book in the hope that it will be useful to those interested in the intriguing problems of the Sympathetic Nervous System It sets forth an account of our work and experiences in the Surgical Unit of St Bartholomew's Hospital, some of which have been described in the Bradshaw Lecture and an Hunterian Lecture at the Royal College of Surgeons

We have been at pains to describe in some detail the Anatomy and Physiology as far as we know it, in the hope that others may be spared the trouble we have taken in assembling from many sources the fundamental knowledge of the functions of the Sympathetic System, without which the logical basis of sympathectomy cannot be understood The operations in general use have been described, though not in great detail, for they do not present any technical difficulty to surgeons well versed in the anatomy of the parts Details of the operations, if required, can be found in the original descriptions, references to which are given

The main feature of the book is the attention which has been given to the much more difficult task of selecting the cases for operation, the investigations necessary to determine those which are suitable, and the physiological considerations underlying the clinical problems they present

We have also tried to estimate the value of sympathectomy in the treatment of various diseases In quoting the experience of others we have selected as far as possible the papers which describe the late, as distinct from the immediate, effects of the operations, and this explains the small number of our references, for few clinics are capable as yet of furnishing information about the late results of sympathectomy

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ACKNOWLEDGMENTS

A NUMBER of the figures used to illustrate this book have appeared elsewhere, and we wish to express our indebtedness to the authors and publishers who have permitted us to reproduce them

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We have Dr Alfred W Adson's permission to use his illustrations of the posterior approach to the cervicothoracic ganglia, and of the transperitoneal exposure of the lumbar ganglia, Figs 17 and 18 having been published in vol xi of the *American Journal of Surgery*, and Figs 24 and 25 in vol xlviii of *Surgery, Gynæcology and Obstetrics*

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It would take too long to thank all those from whom we have gained knowledge, and we hope that none of those who have preceded us will regard absence of acknowledgment as lack of appreciation

G E G
J P R

St Bartholomew's Hospital
November 1933

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dissection represented in Fig 13, to Miss Barclay-Smith for several of the drawings and diagrams, and to Miss Margaret Vaughan for photographs of patients and specimens

Finally, we would like to thank Mr A A Tindall for his kindly co-operation and advice in the production of the book

CONTENTS

CHAPTER IV

LIST OF ILLUSTRATIONS

CHAPTER IV

SURGERY OF THE SYMPATHETIC NERVOUS SYSTEM

CHAPTER I

ANATOMY AND PHYSIOLOGY

In recent years a vast amount of research has been devoted to the gross anatomy and histology of the sympathetic nervous system, and it would be tedious, as it would be unnecessary, to recapitulate here what is known about the whole system. Merely an outline, therefore, will be given to indicate the anatomical and physiological principles which underlie the surgical operations now commonly performed upon certain portions of the sympathetic system. As anatomical and physiological knowledge advances, the scope of surgery will become wider, and surgery in its turn is likely to prove a valuable method of investigating the problems of the structure and function of the sympathetic system in man.

It must also be clearly understood that this work deals only with the sympathetic or thoraco-lumbar portion of the autonomic nervous system, the cranial and sacral portions being left out of consideration.

Historical Note.—In days gone by it was believed that the cervical sympathetic nerve sprang, as its close neighbour the vagus was known to do, from the brain, and this was the current belief till François Pourfour du Petit published his epoch-making experiments in 1727. The paper was entitled "Memoire dans lequel il est démontré que les nerfs intercostaux fournissent des rameaux qui portent des esprits dans les yeux." He severed the vago-sympathetic trunk ("nerf intercostal") of dogs, and showed that immediately after the

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section changes which we have now learnt to associate with paralysis of the cervical sympathetic are observed He interpreted his results in the terms of contemporary physiology, believing that the operation had prevented the flow of animal spirits from the posterior to the anterior parts of the body, but the important thing to note is that his work disproved the hitherto accepted notion that impulses were passing from the head towards the trunk in the cervical sympathetic

The Danish anatomist Winslow published his "Exposition Anatomique" in 1732, and in it he describes the ganglia present upon nerve trunks, apparently including the sympathetic ganglia, as small subordinated brains, thus paving the way for Bichat, one of the four great vitalists, who seventy years later put forward the conception of two independent nervous systems in the body The brain and spinal cord seemed to him to be concerned with the outside world, while the second system was concerned with the internal economy and nutrition of the body, and was controlled by the sympathetic ganglia, with the solar plexus as the centre of the entire sympathetic system

Though Bichat's idea of sympathetic control had an element of truth in it, his error in conceiving the cerebrospinal and sympathetic systems as entirely independent was exposed by the observation that the two systems were in anatomical continuity through the rami communicantes, which, *according to his view, ought not to exist* The gradual accumulation of knowledge in regard to the rami communicantes starts with the stupendous figure of Albrecht von Haller, the greater part of whose work was done a quarter of a century before Bichat was born, and it may be traced through Johannes Muller, whose histological researches established the nature of the fibres composing them, to Gaskell and Langley, whose animal experiments established the nature and effects of the impulses which they transmit

Anatomical Outline

In order to obtain a comprehensive view of the anatomy of the sympathetic system it is well to commence with the more peripheral and better-known portions of the system, and afterwards to deal with the central controlling mechanisms, the exact location and function of which are still incompletely explored, though information about them is steadily accumulating

The Preganglionic Fibres —The grey matter in all the thoracic and in the upper three lumbar segments of the spinal cord differs from that at other levels, possessing a lateral horn in addition to anterior and posterior horns In this lateral horn are the cells which Gaskell named connector cells, whose axons leave the spinal cord in the anterior roots of all the thoracic nerves and the upper three lumbar nerves These axons are medullated fibres, which can be distinguished from the axons of the anterior horn cells by their small size, being 2 6 μ or less in diameter They leave the anterior spinal roots in the white rami communicantes, and so reach the gangliolated sympathetic trunks, where some of them end by arborizing round ganglion cells, though they may travel past several ganglia either up or down the trunk before reaching their termination Others pass through and away from the gangliolated trunk, being unaltered in their passage, to end around cells in the outlying visceral ganglia, while a few run as continuous fibres from the grey matter of the spinal cord, through the gangliolated trunk, to the medulla of the suprarenal gland Because they convey impulses from the spinal cord to the ganglion cells of the sympathetic system these fibres were named by Langley preganglionic fibres

The Gangliolated Trunks — The gangliolated trunks extend, on either side of the vertebral column and in close relationship to the bodies of the vertebræ, from the base of the skull to the coccyx (Frontispiece) Each trunk consists of fine medullated preganglionic fibres, and of large ganglion

cells which are grouped together at intervals along the trunk to form the ganglia, which correspond approximately in number to the spinal nerves in the various regions of the cord, the cervical region being exceptional in that there are only three ganglia (superior, middle and inferior) In the thoracic region there are eleven or twelve ganglia, four in the lumbar and usually four in the sacral region The ganglia of the main trunks are concerned with the sympathetic innervation of the extremities, the head and neck, and the thoracic viscera, and they have nothing to do with the innervation of the abdominal viscera

Since preganglionic fibres arise only in the thoracic and upper lumbar regions it is clear that to reach the cervical and the lower lumbar and sacral ganglia the preganglionic fibres must travel for considerable distances either up or down the trunk, though in the thoracic region some of the preganglionic fibres issuing with a certain anterior spinal root may terminate in the corresponding ganglion of the sympathetic trunk

The Visceral Ganglia—In the abdomen the ganglion cells whose axons pass to the abdominal viscera are aggregated into ganglia, the most important of which are the cœliac, the superior mesenteric and the inferior mesenteric ganglia, which lie upon the anterior aspect of the aorta close to the origin of its visceral branches Bundles of nerve fibres run to these abdominal ganglia from the ganglionated trunks in the lower thoracic and the lumbar regions, being named thoracic splanchnic and lumbar splanchnic nerves respectively, but it must be clearly understood that these bundles are composed of medullated preganglionic fibres which have passed through the ganglionated trunk without interruption (Fig 1)

The Postganglionic Fibres—The ganglion cells of both the trunk ganglia and the visceral ganglia around which the preganglionic fibres arborize are known as excitor cells, and from them their axons, which are Langley's postganglionic fibres, pass to their ultimate destination in bloodvessels,

PLATE II

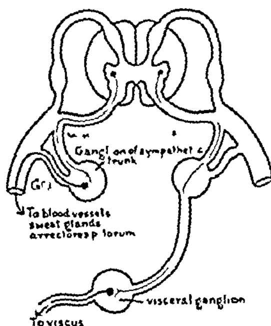


Fig 1 —Diagram illustrating on the Left Side the Path to the Periphery and on the Right the Path to the Viscera (Preganglionic Fibres Green, Postganglionic Red)

Note on the right side the long course of the preganglionic fibre through the ganglion of the lateral trunk and thence by way of the splanchnic nerve to the visceral ganglion

[To face p. 4

sweat glands, the eye, the thoracic and abdominal viscera—in fact, to every structure innervated by the sympathetic The postganglionic are the sympathetic fibres proper, being in great part, if not entirely, non-medullated Bundles of postganglionic fibres are given off from all the ganglia of the trunks to join the spinal roots, and every spinal nerve is thus provided with a sympathetic supply These bundles are known as grey rami communicantes

The Rami Communicantes—There are fourteen or fifteen white rami communicantes of the sympathetic system on each side, connecting the anterior spinal roots of the thoracic and upper two or three lumbar segments with the gangliated trunks They contain the preganglionic fibres, and provide the pathway whereby all sympathetic impulses leave the spinal cord

The grey rami communicantes are much more numerous, two or more rami passing to every spinal nerve from the gangliated trunks They are composed for the most part of unmyelinated postganglionic fibres which are distributed through the spinal nerves to the bloodvessels, sweat glands and arrectores pilorum muscles of the head, neck, trunk, and limbs No impulses pass along the grey rami to the thoracic or abdominal viscera

The grey rami also contain myelinated fibres, the origin and function of which is still a matter of controversy They may be afferent fibres entering the sympathetic trunks, but the problem does not appear to be of practical importance in surgery

Sympathetic Supply to the Head—This account of the general plan of the system will be elaborated in so far as the anatomy of the organs so far subjected to surgery is concerned

The bloodvessels and glands of the head and neck, and the eye, are supplied from connector cells in the first and second thoracic segments, whose preganglionic fibres leave the cord in the white rami communicantes of the first and second

PLATE III

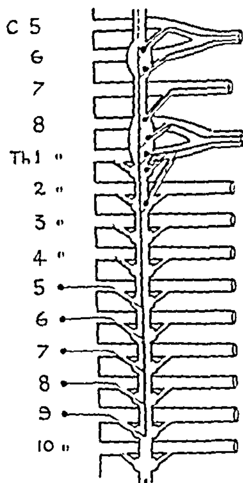


FIG 2 —DIAGRAM TO SHOW THE ORIGIN OF THE SYMPATHETIC SUPPLY TO THE UPPER EXTREMITY (PREGANGLIONIC FIBRES GREEN, POSTGANGLIONIC RED)

Note postganglionic fibres arising from the second thoracic ganglion and joining the brachial plexus (Kuntz s nerve)

[To face p 6

thoracic nerves, and passing up the thoracic and cervical portions of the sympathetic trunk, end around excitor cells in the superior cervical ganglion Many of the postganglionic fibres pass thence along the branches of the internal and external carotid arteries, but others accompany branches of the cervical plexus to reach their destinations

Supply to the Arm—It is not known for certain which thoracic segments contain the connector cells for the arm, but they must lie in the mid-thoracic region from as high perhaps as the fourth segment to as low as the ninth The preganglionic fibres pass out in the white rami communicantes from these segments and ascend the thoracic trunk to end in the middle and inferior cervical, and the first and second thoracic ganglia Grey rami in numbers which vary greatly in different individuals pass from these ganglia to the brachial plexus, and the postganglionic fibres are distributed to the limb with the branches of the plexus (Fig 2) Careful dissection of the brachial plexus may reveal any number from twelve to seventeen or more grey rami joining its roots from different sympathetic ganglia, running in different directions and appearing in different planes in different individuals The surgical importance of this lack of uniformity in the anatomical arrangement of the grey rami will be referred to in greater detail in a later chapter

Supply to the Leg—The sympathetic supply to the leg has its connector cells in the lowest three thoracic and the upper three lumbar segments, the preganglionic fibres passing out in the six lowest white rami communicantes, and ending in the second, third and fourth lumbar, and in the sacral ganglia The grey rami communicantes from the second lumbar ganglion downwards contain postganglionic fibres which are carried to the periphery by way of the lumbar and sacral plexuses of the spinal nerves (Fig 3) It is therefore clear that if the second, third and fourth lumbar ganglia and the intervening portions of the trunk be removed, the excitor cells to the lumbar nerves and the preganglionic fibres to the

PLATE IV

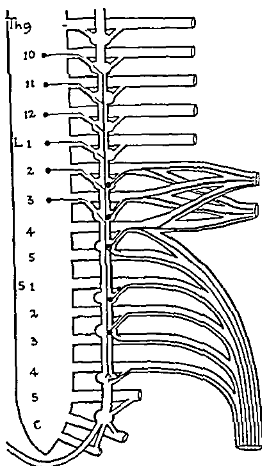


FIG 3 —DIAGRAM OF SYMPATHETIC SUPPLY TO LOWER EXTREMITY (PREGANGLIONIC FIBRES GREEN POSTGANGLIONIC RED)

The postganglionic fibres are joining the roots of the anterior crural obturator and sciatic nerves

sacral nerves will be removed or divided, and sympathetic denervation of the leg will thus be achieved

Supply to Thoracic Viscera—The connector cells for the thoracic viscera lie in the third and fourth thoracic segments, the preganglionic fibres running upward in the thoracic and cervical portions of the trunk to the superior, middle and inferior cervical ganglia, whence the excitor cells send their postganglionic fibres to the heart and lungs by way of the cardiac branches of these ganglia

It will be apparent that this constitutes an exception to the rule that ganglia of the trunks are concerned entirely with somatic, and not with visceral innervation The cervical ganglia are, in fact, combined somatic and visceral ganglia The cervical portion of the trunk is a combination of the preganglionic fibres which control somatic ganglion cells, and preganglionic fibres controlling thoracic visceral ganglion cells which lie in the cervical ganglia The cervical sympathetic trunk may be regarded, therefore, as a superior splanchnic nerve, as well as being a part of the lateral sympathetic trunk

Supply to Abdominal Viscera—The abdominal viscera are innervated through a complicated arrangement of ganglia which receive their preganglionic fibres through the thoracic splanchnic nerves, and also through the splanchnic branches of the lumbar sympathetic trunks

The connector cells whose fibres pass to the upper abdominal ganglia lie in the lower six thoracic segments of the spinal cord Their preganglionic fibres reach the ganglionated trunks in the corresponding white rami communicantes, but they leave the trunks without forming any synapses therein and travel in the splanchnic nerves to the ganglia, the most important of which are the cœliac (semilunar), the superior mesenteric, and the aorticorenal ganglia, where they terminate in arborizations around the ganglion cells From the latter, which are the excitor cells, postganglionic fibres are distributed along the bloodvessels to the

PLATE IV

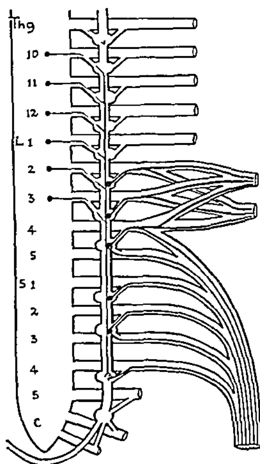


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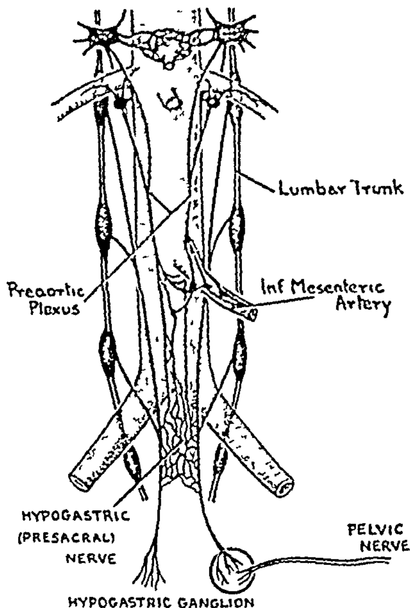


FIG 4—FORMATION OF THE LUMBAR SPLANCHNIC NERVES, THE PREAORTIC PLEXUS AND THE PRESACRAL NERVE

The contributions from the lumbar ganglia to the inferior mesenteric plexus are not shown, but these nerves are illustrated in the dissection (Fig 36, p 118)

stomach, to the small intestine and the first part of the colon, and to the kidneys

The supply to the suprarenal bodies is peculiar, for though it appears at first sight that the suprarenal and the kidney have a common source of supply, the fibres going to the kidney are postganglionic, whereas those to the suprarenal have passed through the ganglia without interruption and are still the preganglionic axons of the connector cells (Frontispiece)

Below the origin of the superior mesenteric artery a plexus is formed in front of the aorta, the aortic or intermesenteric plexus, being composed of nerves which run downwards from the cœliac ganglia, with the addition of branches which pass inwards from the lumbar trunk on each side It is important that the nature of these lumbar visceral (splanchnic) branches should be clearly understood They consist of preganglionic fibres originating in the first three lumbar spinal segments, joining the lumbar trunk in the usual way *viâ* the white rami communicantes, but passing through the trunk without interruption, and thus forming a continuation of the splanchnic nerve series into the lumbar region

The aortic plexus sends out prolongations which clothe the branches of the aorta, and it also furnishes the central root of the hypogastric plexus (presacral nerve) (Fig 4)

In the aortic plexus immediately below the origin of the inferior mesenteric artery there is an aggregation of ganglion cells known as the inferior mesenteric ganglion, and from it postganglionic fibres accompany the branches of the artery to supply the lower part of the colon and the upper part of the rectum (Fig 36, p 118) In man the inferior mesenteric ganglion is a less conspicuous and less important structure than it is in the lower animals, for in them the cell station of the sympathetic supply for the whole of the lower bowel and bladder is situated in this ganglion In man it is not

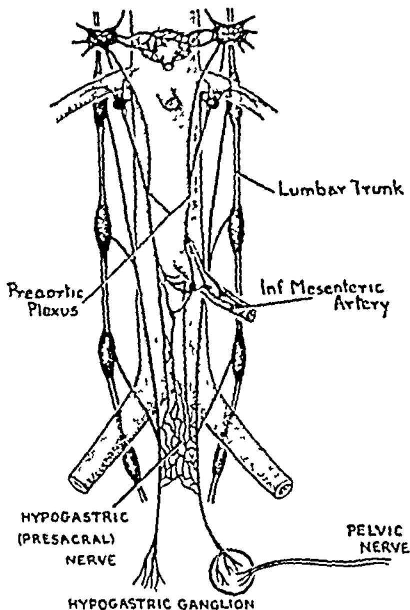


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always possible to define the ganglion at all clearly, and the ganglion cells from which the postganglionic fibres arise to supply the rectum and bladder are widely distributed along the course of the hypogastric plexuses and are to be found as low down as the lateral aspect of the rectum

The lower rectum, the bladder and the uterus receive their sympathetic supply by way of the inferior hypogastric (pelvic) plexuses which arise above from three roots The central root which descends over the bifurcation of the aorta from the aortic plexus has been referred to above, and this is joined on each side by a lateral root, formed by the junction of the lumbar splanchnic branches, which crosses the corresponding common iliac artery at its origin The three roots form a plexus just below the bifurcation of the aorta, lying upon the fifth lumbar vertebra and the disc between it and the sacrum, the plexus being called the hypogastric plexus, or more commonly the presacral nerve (Fig 4) The presacral nerve descends into the pelvis and divides into the two inferior hypogastric or pelvic plexuses which run down to the lateral walls of the rectum The pelvic plexuses also receive the sacral autonomic (pelvic) nerves

The preganglionic fibres for the lower part of the large intestine and for the bladder arise from connector cells in the upper three lumbar segments, and end in the inferior mesenteric ganglion and the ganglionic tissue distributed throughout the hypogastric plexuses, from which the postganglionic fibres are distributed The preganglionic fibres for the rest of the pelvic organs pass direct to the walls of the viscera and arborize round excitor cells therein

Summary of Anatomy—The unit which is responsible for activating the structures which are controlled by the sympathetic system is the excitor cell and its postganglionic fibre As a general rule, the only exception being the cervical ganglia, the ganglia of the sympathetic trunks contain excitor cells which innervate only the somatic structures The excitor cells for the viscera, again with the one exception of

the thoracic viscera, lie in ganglia outside the ganglionated trunks (Fig 1)

All the excitor cells, wherever situated, are under the control of preganglionic fibres which are the axons of cells in the lateral horn of grey matter in the thoracic and upper lumbar regions of the spinal cord Preganglionic fibres also innervate the medulla of the suprarenal bodies

Functions of the Sympathetic System

Cannon[1] has recently announced his belief that the ultimate function of the sympathetic system is to preserve the constancy of the fluid matrix of the body, or, in other words, that the sympathetic system is responsible for the control of the internal economy of the body, while the cerebrospinal system is concerned with the reactions of the body to its external environment This conclusion, drawn from prolonged and profound experimental study, sounds at first curiously like the view held by Bichat, the fundamental difference being, of course, that it is now known that the two systems are not independent of each other It is suggested, in fact, that the sympathetic ganglia may act in some respects as electrical transformers The nerve impulses from the cerebrospinal system, though appropriate for skeletal muscle, may not be so for plain muscle and secreting glands, but it is possible that in passing through the ganglia their character may be changed so as to render them capable of stimulating these structures

The most powerful stimuli to the sympathetic system arise from hæmorrhage, cold, anoxæmia, muscular work, and emotion, especially fear The response to hæmorrhage is increased coagulability of the blood, and peripheral vasoconstriction, to cold the response is again vasoconstriction, but in addition erection of hairs or feathers takes place in order to conserve the body heat, and metabolism is increased by outpouring of adrenalin Anoxæmia produces tachy-

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had its cause in the stomach, anger in the liver, kindness in the heart and joy in the intestine!

Professor Langdon Brown summarizes the account of the emergency sympathetic action by saying that it is designed to prepare the animal for fight or flight, and Cannon has pointed out how the numerous effects of stimulation are well planned to mobilize rapidly and completely the forces of the body for its defence. The pupil is dilated, and so the visual field is increased in order to give warning of flank attack; the appearance of goose skin is the vestigial remnant of the mechanism whereby the hair-covered animal is able to make itself appear larger and more formidable to its antagonist; the arteries become contracted, the blood pressure is raised and the heart beat accelerated, the combined effect being to increase cardiac efficiency; the spleen contracts and squeezes out a reserve of blood cells into the circulation; glucose is liberated from the liver to supply the needs of the active muscles; the bronchi are dilated to increase the oxygen supply to the lungs; and the adrenal medulla pours out its secretion, which enhances all the efforts already produced by sympathetic stimulation.

Considering the widespread distribution of the phenomena which appear to be co-ordinated and designed to one end, and that the train may be fired by an emotional stimulus, it is not surprising that recent animal experiments and clinical observations show that central control resides in the diencephalon, the controlling centres being acted upon in their turn by various impulses from higher centres in the cerebrum and possibly also influenced by hormones.

The study of comparative anatomy shows that the sympathetic system is acquired comparatively late in the process of evolution, and in its earliest forms it consists, not of nerve plexuses, but of a widespread distribution of adrenalin-producing tissues. As the scale is ascended the plexuses and ganglia become more conspicuous and extensive, while the adrenalin-producing cells become more and more aggregated,

cardia, a rise of blood pressure and contraction of the spleen, and as a result of muscular work there is a rise in the sugar content of the blood, the sugar being liberated from storage, dilatation of the bronchioles takes place to admit greater amounts of oxygen to the lungs, and vasodilatation and sweating occur in order to regulate body temperature—all in response to the activity of the sympathetic system

It must be supposed that these functions are constantly being exhibited, and when adequately antagonized by the cranial and sacral autonomic systems they are responsible for regulating visceral activity, and for maintaining the fluid equilibrium, the body temperature and the reaction of the blood

Any departure from the normal state will call forth reactions in which sympathetic activity may be recognized For example, should the blood sugar fall below 70 mgms per cent the hypoglycæmic reaction ensues, the pupils dilate, the skin becomes pale, the blood pressure rises and the patient sweats, these phenomena being evidences of sympathetic stimulation, and being accompanied by outpouring of adrenalin which leads to conversion of glycogen to sugar and a restoration of the sugar level in the blood

Controlling Mechanisms—Were this the only function of the sympathetic system, one could imagine its control and co-ordination existing at a level no higher than the spinal cord, or even the solar plexus But in addition to this constant activity there is the emergency action, which is generally acknowledged to be undoubtedly and dramatically an expression of the whole system at the height of its power, being produced by emotional and psychic stimuli which involve reactions in consciousness, and suggest to the modern physiologist a cerebral controlling centre It is interesting to reflect that even the emotional factor, though recognized by Bichat, could be interpreted in the light of physiological theories of his day without implicating the brain—for fear

influence exerted upon the centres in the medulla and spinal cord by the diencephalon

Cerebral Control—Among the best known of the classical experimental animals is Goltz's dog, which, being deprived of its cerebral cortex, corpora striata and dorsal thalamus, was still capable of carrying on a fairly satisfactory existence, but was readily roused to anger on the slightest provocation Later Cannon found that the "sham rage" which appeared after disconnection of the cortex from the brain stem was associated with all the evidences of sympathetic excitation

The subject has been followed up further by Philip Bard,[2] who localized this centre of sympathetic control rather more accurately by demonstrating that the sham rage which appears after ablation of the cerebral hemispheres, corpora striata and anterior half of the diencephalon, fails to develop when the brain stem is transected at the posterior extremity of the diencephalon, or through the anterior end of the mesencephalon He concludes from this that the mechanism is mediated by the posterior half of the hypothalamus and the most ventral and posterior portions of the corresponding segment of the thalamus This, then, is the position of the highest control of the whole sympathetic system, and Bard believes that it controls not only the medulla, but the cord as well He summarizes his views by stating that the preganglionic neurons in the lateral horns of the thoracic and lumbar cord are under the control of supraspinal influences This control may be continuous, or may be set in action under special conditions by circulatory, metabolic or reflex influences Functionally similar groups of preganglionic fibres have bulbar controlling centres, and dominating all is the centre in the diencephalon capable of discharging all the lower ones, being brought into action during stress or emergency (Frontispiece)

Bard's work receives confirmation from the experiments of Beattie, Brow and Long,[3] who, approaching the subject from a slightly different angle, have arrived at the same

being finally concentrated in the human adult in the suprarenal bodies

An impulse travelling along a postganglionic fibre will activate merely the organ, be it gland cell or muscle fibre, in relation to which the fibre ends The nerve terminals are pericellular, not intracellular, and it is now believed that between the nerve ending and the structure it innervates a substance is liberated by the nerve impulse which Cannon calls " Sympathin," and which is either adrenalin itself or a body which bears a very close resemblance to it

Langley was able to show that preganglionic fibres from a single spinal nerve pass to several ganglia in the sympathetic trunk, and therefore impulses passing along such a bundle of fibres as a single white ramus communicans will create a widespread effect by acting upon many excitor cells and, through their postganglionic fibres, upon many organs It will thus be seen that if the reaction involves the system as far towards the centre as the spinal cord the result may be a fairly diffuse response

Passing still further towards the chief controlling centre, when the medulla is reached certain centres are to be found which are part of the sympathetic apparatus These are the vasoconstrictor and vasodilator centres, the cardio-accelerator centre and the centre for carbohydrate metabolism, and that for the supreranal mechanism Elliott pointed out that preganglionic fibres pass through the cœliac plexus to end in the medulla of the suprarenal glands , and as Langley's doctrine that the action of adrenalin is the same as that of stimulating postganglionic fibres is universally accepted, it follows that when impulses pass along these suprarenal preganglionic fibres the effect upon the body is more widespread than ever

Once more, from this different angle of approach, we return to the central mechanism controlling the whole system, and a brief reference will be made to the considerable amount of work which has recently been carried out to show the

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conclusions, and have advanced our knowledge of the anatomy of the system by indicating the path followed by the impulses which pass from the hypothalamus to the spinal cord It was shown by Levy that the development of cardiac irregularities (extrasystoles) in an animal anæsthetized with chloroform is dependent upon the intactness of sympathetic neurons These extrasystoles were abolished, in the experiments performed by Beattie, Brow and Long, by section of the hypothalamus in a plane between the anterior edge of the corpora quadrigemina and the posterior edge of the pituitary fossa They also demonstrated extrasystoles and other pressor effects as a result of stimulation of the lateral wall of the third ventricle in an animal under chloroform Further, a lesion in the posterior part of the hypothalamus was shown by them to produce degenerative changes in fibres passing down through the brain stem, medulla, and spinal cord to end in the lateral horn of the grey matter of the thoracic and upper lumbar regions

More recently Beattie discovered a centre in the hypothalamus, stimulation of which produced dilatation of the pupil With Duel and Ballance[4] he carried out a series of experiments in which the peripheral ends of various motor nerves in the neck were anastomosed to the cervical sympathetic, and after the period required for regeneration had elapsed the hypothalamic pupillodilator centre was stimulated electrically The result of this stimulation was to produce the appropriate motor effects in the distribution of the nerves anastomosed to the cervical sympathetic, thus establishing the continuity between the hypothalamus and the lower levels of the sympathetic system

Animal experiment, though instructive and extremely helpful as a guide to the study of human physiology, cannot be as convincing as clinical experience, and in this instance the final link in the chain of evidence is provided by a most remarkable case recorded by Penfield[5] His patient was a woman who suffered from repeated attacks, or fits, each of

which reproduced faithfully the events of its predecessors, not only in kind, but also in the order of their appearance, thus fulfilling the criteria of the focal discharges through the cerebrospinal system described by Hughlings Jackson as epileptic In the milder attacks the patient remained conscious, and it was only when they became severe, and finally continuous shortly before death, that consciousness was lost

The seizures started by the patient asking to be given ice to suck, and at the same time her face and arms were seen to

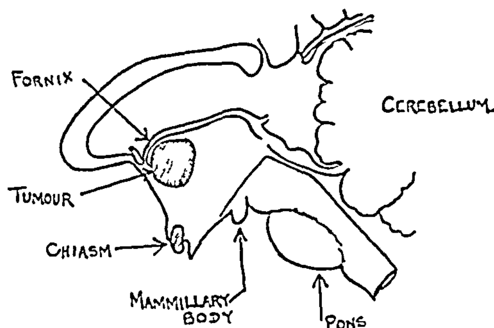


FIG 5 —TUMOUR OF THIRD VENTRICLE CAUSING DIENCEPHALIC EPILEPSY
(Redrawn from Penfield)

flush a deep red Respiration was slowed, tears flowed from both eyes, sweat appeared all over the body, and saliva ran out of the mouth The pupils became dilated, and in some attacks the eyeballs protruded At first the pulse was strong and rapid, then the flush faded and the pulse became weak and slow The woman would then hiccough a few times, would shiver slightly, and the breathing would become irregular The attacks were sometimes attended by the appearance of goose flesh on the arms, and were followed by constipation and inability to empty the bladder

Finally the patient died after a prolonged series of fits, and autopsy revealed a tumour (cholesteatoma) of the choroid plexus hanging in the antero-superior part of the third ventricle, protruding into the foramina of Munro and producing internal hydrocephalus (Fig 5) Its free mobility probably accounted for the intermittent nature of the symptoms The tumour pressed upon the mesial anterior and superior aspect of the thalamus on each side, and here there was œdema, while histological examination of the area revealed fading out of cell structure and some local hyperæmia

Though Penfield did not presume to single out any of the many named nuclei in this region as the ones responsible for the phenomena observed, it is significant that this tumour was situated close in front of the position defined by Bard, and also by Beattie, Brow and Long, as the diencephalic controlling centre of the sympathetic system, and there is no doubt that the clinical manifestations described by Penfield correspond to the effects of sympathetic stimulation

It has been remarked already that the bodily responses to sympathetic stimulation are those best adapted for its defence, or for those offensive reactions which may be required to combat an enemy The behaviour of an animal exhibiting fear or rage is a primitive reaction, which is therefore dependent on the older divisions (in respect of evolution) of the central nervous system, a reaction which can take place independently of the more recently acquired cortical mechanisms The thalamus can appreciate and differentiate between the pleasant and the harmful afferent impulses, and no more detailed analysis of sensation is required to excite a reflex discharge from the neighbouring hypothalamus, and the mere reception of an impulse resulting from a painful sensation is sufficient to elicit a response

It is sometimes assumed that the cortex initiates the emotional discharges of rage, but, as has been remarked already, if an animal deprived of its cortex be exposed to comparatively

feeble stimulation a terrific reaction ensues This means that the influence of the cortex upon the diencephalon must be to limit its stimulation by analyzing more thoroughly the afferent impulses flowing into the brain, discriminating between those that are harmful enough to call for a defensive or offensive reaction and those which are not, and to inhibit the activity of the diencephalon That "anger is short madness" is thus borne out by physiological experiment, though the physiologist might prefer to state that rage is the expression of the activity of a lower motor level released from its higher control These considerations have an important bearing upon the subject in hand, for in many of the disorders of the sympathetic system emotional factors seem to play a prominent part

A complete survey of the sympathetic system must therefore begin with the controlling centre in the hypothalamus, and the tracts passing therefrom to the lower centres in the medulla and the thoracic and lumbar regions of the spinal cord These centres in the cord, which not only respond to impulses from above, but are also capable of independent action, are the seat of origin of the preganglionic fibres, which, in their turn, control the activity of the various sympathetic ganglia

Sympathectomy as an Experiment in Human Physiology — Our understanding of the functions of the human sympathetic nervous system is very imperfect, for clinical experience not only reveals gaps in our knowledge, but also casts grave doubt upon many current beliefs

Though it would be deplorable to detract in any way from the honour due to the great physiologists of the past for their early investigations, it is important to realize that the accepted ideas with regard to the sympathetic system in man have been derived from experiments upon the lower animals, whose nervous system in general, and whose sympathetic system in particular, differ in many respects from the human It is only since surgery, the most fruitful method of research

into the problems of human physiology and pathology, has embraced the sympathetic system, that we have begun to gain accurate information about its activity in man. Our debt to the physiologists lies in the encouragement and the direction which their animal experiments have given us in recognizing general principles, in devising operative procedures, and in showing how accurate observations may be recorded.

The collection and careful analysis of the information obtained by accurate methods of observation of patients, and more especially of patients before and after an operation has been performed upon some portion of the sympathetic system, will bring to light facts which can be proved by no other method of research, and will be the foundation for hypotheses to be tested by further surgical investigation.

Those who choose to pursue this line of research are confronted by two great difficulties. The first is that it appears to be possible to remove certain portions of the sympathetic system which had come to be regarded as essential for the regulation and control of important viscera, and had even been thought to be of vital necessity to the body, without any apparent ill effect. It is improbable that man could afford to lose as much of his sympathetic system as can the lower animals, but Cannon has been able to show that cats, dogs and monkeys deprived of the whole of their ganglionated trunks from stellate to sacral ganglia on both sides can continue to live quite comfortably for months or years in the sheltered surroundings of the laboratory. Young animals will grow symmetrically after unilateral sympathectomy. The effects of total sympathectomy are shown, however, in a lowered basal metabolic rate, a reduced capability for work, a dramatic fall in blood sugar during exercise, and great sensitiveness to insulin. Emotional stimulation, such as the fear of an antagonistic animal, at once reveals its weakened offensive and defensive reactions, and lack of adaptability to changes in its environment is shown by the severe drop in

body temperature and the intense shivering produced by cold, and by the ease with which heat-stroke may be precipitated by moderately high temperatures These changes occur only in animals who have suffered what amounts to total sympathectomy, and seeing that the effects when the animal is living under normal conditions may be negligible, the estimation of the lesser effects of partial sympathectomy in man may present considerable difficulty

The second fact that has to be borne in mind in regard to this form of research is that surgical experiments may take months or even years to yield their results, and the patient seeker after the truth must resist the temptation to accept the ofttimes striking immediate result of an operation as the true effect of sympathectomy A large number of our present impressions are founded upon incomplete experiments, and the impressions may require to be revised and modified many times before they develop into conclusive evidence

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CHAPTER II

SYMPATHECTOMY FOR DISORDERS OF THE CIRCULATION

There are many conditions associated with faulty nutrition of the peripheral portions of the limbs in which organic occlusion of the vascular supply does not appear to be the true explanation of the phenomena, and in which it seems more reasonable to postulate a diminution in the lumen of the vessels owing to contraction of the muscular coat rather than by disease of the walls This conception underlies the various operations which have been designed to alter the calibre of vessels through the medium of the vasomotor nerves, and thus to improve the blood supply to the tissues concerned

The existence of nerve fibres and nerve endings in the outer and middle coats of arteries has long been recognized, and the credit for being the first to think of applying this knowledge to surgery belongs to Alexander, of Liverpool, who published in 1889 his experience of the treatment of epilepsy by cervical ganglionectomy, and to Jaboulay, of Lyons, who in 1899 stripped off the outer coat of the femoral artery as the treatment for perforating ulcer of the foot

In reviewing the events which led up to the operations of ramisectomy and ganglionectomy for vascular disease it is necessary to go back to 1909, when Boeke described a system of accessory non-myelinated nerve fibres to striated muscle He found that these nerves supplied muscle fibres which were also innervated by medullated nerve fibres, and since they did not degenerate when the anterior spinal roots were cut he concluded that they sprang from the sympathetic system

Subsequently Kulchitsky found that these sympathetic fibres supply separate muscle fibres, and the view came to be held that the muscle fibres innervated by the sympathetic are concerned with "plastic tone," and those supplied by somatic nerves with what has been termed "contractile tone" Since these views were first stated an enormous amount of work has been carried out in order to try to confirm both the histological findings and the conceptions in regard to the function of these fibres It is sufficient to say that Boeke's dual innervation, instead of being universally distributed, could be shown to exist in only a few of the voluntary muscles, that in the muscles of the limbs no innervation other than that of ordinary motor nerves could be made out, and several observers failed to affect the tonic contraction of decerebrate rigidity by cutting the sympathetic supply in the cat

This may be taken to represent the position when Hunter and Royle began their work on decerebrate rigidity and upon spastic states in man They found that if they altered the technique of the experiment on the cat by cutting the sympathetic supply to a limb first, and then some time later decerebrating the animal, the limb deprived of its sympathetic supply failed to maintain its posture for as long a period as the others, and this they attributed to loss of "plastic tone" It has been suggested in criticism of their experiment that the loss of sympathetic impulses some time before decerebration resulted in a loss of some trophic factor without which the muscle is unable to carry out its tonic reactions so well, and that this effect might be an indirect one acting through alteration of the blood supply to the muscles More recently Phillips[1] has come to the conclusion that the diminution in the tone of skeletal muscle following sympathectomy is apparent rather than real, and that the change which takes place may be due to increased excitability of the afferent nerve endings subserving the lengthening reactions

Hunter's experiments were performed on goats and birds,

but when Royle came to apply the results of their work to the surgical treatment of spastic states in man he was satisfied that he was able to benefit his patients, and the operation was hailed with enthusiasm Unfortunately other surgeons have been unable to achieve the benefit claimed by Royle, and the operation for spasticity has fallen into disrepute[2] But it had been noted by Royle, and it was also recorded by others who carried out this operation of section of the grey rami, that the extremity so deprived of its sympathetic supply showed evidence of vasodilatation and was warmer than its fellow Thus, arising as a kind of by-product of an operation which, founded upon doubtful anatomical and physiological conjecture, was in itself a failure, the idea of sympathectomy for abnormalities of the vasomotor mechanism, and for various conditions in which increase in the peripheral circulation is desirable, has developed into an operation which, with certain modifications, is of established value in well-selected cases

1 Selection of Cases Suitable for Sympathectomy

Clinical tests to determine the state of activity of the vasomotor supply are intricate and open to misinterpretation, for errors of technique in a simple investigation may introduce complications which, unless they are recognized and allowed for, will of course lead to false conclusions The complications referred to are the many other factors besides sympathetic nerve impulses which affect the state of constriction or dilatation of bloodvessels, and it is only by the most careful criticism of every experiment, and by controlling every variant, that the true result may be obtained In this matter we must acknowledge our indebtedness to Sir Thomas Lewis, whose thorough, ingenious and painstaking researches in this branch of human physiology and pathology have not only clarified many mysteries, but have also shown other investigators how to work at problems still awaiting solution,

how intricate the problems may be, and how carefully experiments must be controlled

Local Effect of Temperature on Bloodvessels — The various disorders of the vasomotor mechanism which are met with in clinical practice appear to be influenced more by changes in temperature than by any other single factor It is therefore natural to study first the response of the vessel to changes in the temperature of its environment, the best account of the reactions of the skin to cold being given by Lewis,[3] whose observations we have been able to confirm

Moderate cooling to a temperature of 15° to 18° C for fifteen to twenty minutes produces vasoconstriction by a local effect of cold upon the small arteries, and when the local temperature is raised vasodilatation takes place by a similar mechanism It is therefore important to know the temperature of the air around the area which is being tested, and to keep it as constant as possible if the effects of vasomotor innervation are to be studied

It is found that if the fingers be immersed in ice-cold water, or in water at any temperature below 15° C, vasodilatation results, and when the fingers are removed from the cold water a reaction takes place which causes their temperature to rise to a point considerably above that of the uncooled hand This reaction is independent of the sympathetic nerve supply to the limb, for we have been able to obtain it after a radical ganglionectomy which was followed by all the evidences of complete sympathetic denervation, but it does not occur after degeneration of the sensory nerves supplying the cooled fingers It is believed to be due to "H"-substance, a body of the same nature as histamine, or possibly histamine itself, liberated locally as a result of an axon reflex for which cold is an adequate stimulus, and which will thus produce local vasodilatation so long as the sensory nerves are intact This reaction is sometimes referred to as "over-cooling," and has to be carefully avoided in all experiments to estimate sympathetic activity, since the vasodilatation, which might be

misinterpreted as due to inhibition of vasoconstrictor fibres, takes place whether the sympathetic supply is intact or not

It may be noted in passing that "H"-substance, whose action is vasodilator, may be present constantly under normal conditions, antagonizing to a certain extent the vasoconstrictor tonus maintained through the vasomotor nerves This conception will be referred to again, for if it be correct it may explain, by postulating variations in concentration of "H"-substance consequent upon changes in the peripheral blood flow, certain alterations observed from time to time in the calibre of the minute vessels of the skin which determine its colour

Influence of Body Temperature upon Peripheral Vessels — Before an operation for sympathectomy is undertaken it is desirable to foretell the amount of benefit which is to be expected from it, and of the various methods employed to make such a forecast the simplest is to observe the degree of peripheral vasodilatation which follows a rise in body temperature This vasodilator reaction is due to inhibition of sympathetic vasoconstrictor impulses as a consequence of the circulation of warm blood to the centres in the cord, and perhaps also to the cerebral centres For experimental purposes the body temperature may be raised either by protein shock, or by heating the body in a hot air bath

Brown[4] has described the reliance he has come to place upon the former method after several years' experience, more particularly in differentiating organic obstruction of arteries from conditions in which the lumen is narrowed by spasm He induces fever by intravenous injection of triple typhoid vaccine, and the surface temperature of the fingers and toes is taken simultaneously with the mouth temperature Normally, after a slight fall, the temperature in the mouth and on the surface rises, and the rise in skin temperature accompanying the febrile reaction approximates pretty closely to that which follows sympathectomy The magnitude of the surface rise depends on the initial temperature of the

extremity, the severity of the febrile reaction, and the patency of the arteries If the rise of temperature in the mouth be subtracted from the rise of skin temperature, the figure so obtained will indicate the change in skin temperature due to movement of blood into the extremity as a result of vasomotor changes

Brown's "vasomotor index" is determined by dividing the above figure by the rise of temperature in the mouth—i e

$$\frac{\text{surface rise} - \text{mouth rise}}{\text{mouth rise}},$$

this index being high in cases of vasomotor disease associated with spasm, but dropping to zero in conditions of organic disease in which vasodilatation is impossible

Typhoid vaccine is the substance most commonly used to induce protein shock, but muscle extracts are also employed both for testing and treating patients who are suffering from vascular obstruction due to spasm

In our hands, however, the alternative of warming the body in a hot air bath, following the plan suggested by Lewis,[6] has given us even more information, we imagine, than could be obtained by protein shock, since the experimental conditions are more directly under our control, and small changes in the behaviour of different digits during vasodilatation may be more accurately observed Skin temperature is recorded by using copper-constantan thermocouples attached to the skin by adhesive strapping So that readings may be taken from several parts simultaneously, the wires from the couples pass through a simple key to the circuit, which includes a galvanometer, and also a vessel of known constant temperature which makes it possible to convert the deflections of the galvanometer into degrees centigrade *

The patient sits in a small chamber made of draught-proof non-conducting material so arranged that with the coverings

* An electrical thermometer which will register rapidly, and is accurate to $\frac{1}{8}$° C, may be substituted for this apparatus

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open the temperature within will remain the same as that of the room, but when the chamber is closed, the coverings being made to fit closely at the neck and wrists (or ankles), the temperature within it may be raised rapidly to 50° C by means of a series of carbon filament lamps The hands, previously cooled by immersion for twenty minutes in a water bath at 15° C, protrude from orifices in the coverings and rest upon a small raised platform of wood or cork so as not to come into contact with the chamber itself (Fig 6) The room temperature should be kept low—just below 15° C is probably the optimum, for at higher temperatures vasodilatation might be produced by external warmth, whereas what we wish to determine is the degree of vasodilatation produced reflexly by heating the body

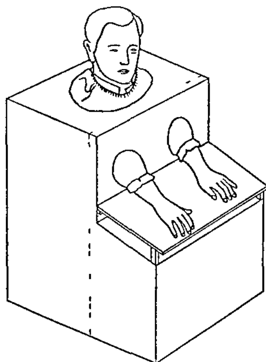


FIG 6—HOT AIR BATH ARRANGED FOR OBSERVING SKIN TEMPERATURE OF FINGERS WHILE BODY IS HEATED

The dotted line indicates the division between the two parts of the chamber When making observations on the feet the front portion consists of a simple upright face with openings to transmit the legs (Lewis in "Heart vol XVI)

It is an easy matter to raise the room temperature if the effect of direct warming of the skin of the extremities has to be tested, but synchronous readings must be taken of the temperature of the room, of the skin of the extremity, and of the hot air bath When these are plotted it is possible to assess the relative importance of the direct effect of external temperature, and of nervous vasomotor

reactions in determining the activity of the peripheral circulation

The accompanying chart (Fig 7) shows the behaviour of a normal individual when tested by this method It will be noted that the room is cool (R T —room temperature 14° to 15° C) In this instance the right hand was tested, the left being used as a control The right hand was therefore immersed at 15° C for twenty minutes, and at the end of that time it was dried without friction, and thermocouples were attached to the middle finger of each hand (R3 and L3) over the dorsum of the distal interphalangeal joint Readings taken during the following ten minutes showed that the temperature of the uncooled fingers was about 18° C, whereas that of the cooled side corresponded to the low room temperature of about 14° C

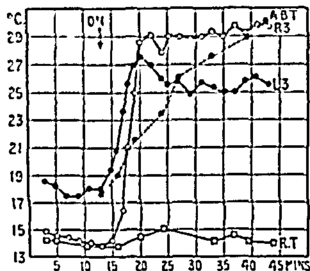


Fig 7.—Chart of Skin Temperature of Fingers, showing Effect of Warming the Body (Normal Response)

Time in minutes R T =room temperature, R3 =temperature of right middle finger, L3 =temperature of left middle finger dotted line A B T =temperature of hot air bath The temperature of the fingers exposed to the cold atmosphere rises rapidly as the body is heated

The coverings of the hot air bath were then closed and the lamps lighted, and as the body warmed up the temperature of both hands rose rapidly, the rise being more rapid, however, on the cooled side, whose temperature finally exceeded that of the control fingers It will be noted that after rising steeply for a time the temperature becomes stabilized at the higher level, and in time even tends to fall slightly The alterations in the shape of this curve—that is to say, the varia-

tions in the rate at which the periphery warms up as the body is heated, which indicate abnormalities in the vessels of the limb—will be referred to later

A few observers have reported favourably on the use of certain drugs, particularly acetylcholine and its allies, which, by their vagomimetic action, have a depressor effect on the bloodvessels The alterations in the vessels all over the body which follow the injection of these substances, though they may be intense enough to distress the patient and alarm the investigator, are of such brief duration that it is extremely difficult to record them with sufficient accuracy to determine their significance, and we have not found the method of any real value

Temporary Paralysis of the Sympathetic—In addition to these methods of inhibiting sympathetic activity, it is sometimes possible to go a step further in the investigation and to produce a temporary paralysis of portions of the sympathetic system by means of local anæsthetic drugs, which may be injected into the peripheral nerves, around the sympathetic ganglia, or into the spinal theca

If 2 per cent novocaine solution be injected into a peripheral nerve—for example, the ulnar nerve at the elbow—it will be noticed that as analgesia appears the vessels of the skin in the analgesic area become dilated, as shown by the skin becoming red and warm It is remarkable how closely the vasodilatation corresponds to the sensory distribution of the nerve injected, and if this dilatation is well marked it may be inferred that the vessels are free from any form of organic obstruction and that a similar degree of dilatation may be expected to follow sympathectomy (*vide* p 44)

This method has been extended by White[7] to deal directly with the sympathetic fibres before they join the peripheral nerves, and he thus temporarily achieves the effect of a sympathectomy, and obtains a very accurate estimate of the result to be expected from operation In the case of the arm he infiltrates the paravertebral tissue by the side of the first

and second dorsal vertebral bodies with local anæsthetic solution, approaching this region from behind One needle is inserted at right angles to the skin surface at a point 4 cms directly lateral to the spine of the seventh cervical vertebra, and passed in until the lower border of the first rib is felt It is slipped just beneath this border and inclined medially at an angle of about 45 degrees and passed onwards till the vertebral body is reached The process is repeated with another needle below the second rib, and when 5 c c of 1 per cent novocaine is injected down these needles the solution bathes the upper end of the thoracic trunk and the inferior cervical ganglion The appearance of Horner's syndrome indicates a successful infiltration

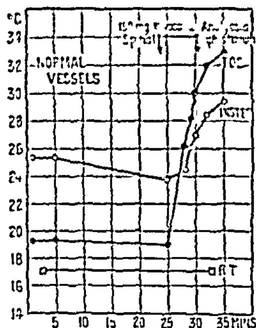


Fig 8 —Chart showing Rise of Skin Temperature in Foot during Spinal Anæsthesia (Normal Vessels)

R T =room temperature Time in minutes The peripheral temperature rises rapidly shortly after analgesia is established, the toes warming up more rapidly than the instep

The leg may be dealt with in a similar manner, the needle being introduced beneath the twelfth rib 7 cms from the midline and passed at an angle of 45 degrees towards the spine till it meets the first or second lumbar body It may then be possible to slide the needle on about another centimetre, and 30 c c of 1 per cent novocaine solution at this point will block the lumbar trunk The alternative method of spinal block is, however, more easily carried out, and is therefore more commonly used when testing the legs (Fig 8)

If a spinal anæsthetic be administered so that the upper limit of analgesia reaches the level of the umbilicus, all the

vasoconstrictor fibres to the legs will be paralyzed Thermocouples attached at different levels on the extremity will indicate the condition of the peripheral as compared with the more proximal vessels, as well as the total increase in the blood flow produced by loss of vasoconstrictor tone The chart (Fig 8) shows the rise of temperature of the second toe and the instep of a patient with normal bloodvessels during the induction of spinal anæsthesia The steep ascent of the curve of the toe temperature and the more gradual but very considerable warming up of the instep are well shown The choice of the drug used to induce analgesia is a matter of little importance as far as this test is concerned, since all the spinal anæsthetic drugs commonly in use cause complete paralysis of vasoconstrictor nerves

Differentiation between Spasmodic and Obliterative Vascular Disease

Raynaud's Disease—Of the conditions which are considered to be due to spasm of the vessel walls the most definite clinical entity is Raynaud's disease, and it will be useful to regard it as typical of the spasmodic in contrast to the organic obliterative diseases of the arteries

The incidence of Raynaud's disease is much greater in women than in men, and its manifestations are most pronounced in the parts of the body which are most subject to cold It is therefore a symmetrical affection of the extremities, the hands usually suffering more severely than the feet, and the ears and nose being rather less frequently involved Though the digits may be cold and discoloured, the pulse at the wrist and ankle, though variable in volume, is always palpable in uncomplicated cases It is characteristic of the disease that the changes in the extremities appear in attacks which occur in response to external cold, but occasionally cases are seen in which the attacks may be precipitated by emotion

In a typical attack the digital arteries contract and the digits become colder than ever, and also become cyanosed The changes in colour will depend upon the condition of the minute vessels of the skin, for while these are open the skin will be blue or violet in colour, but if, as often happens, the minute vessels also pass into a state of spasm, the colour will change to white This blanching of the skin is not, however, an essential feature of the attack, the coldness and cyanosis being the most significant changes As a result of the loss of circulation numbness of the digits ensues, and the patient will complain of a peculiar dull ache which is usually a source of very great distress, especially as the numbness is accompanied by inability to use the fingers for any form of delicate manipulative work, and sometimes even inability to carry out such simple movements as opening a purse or buttoning a coat

As the attack passes off the digits become red, and a very irritating and often painful burning and tingling sensation replaces the numbness If the hands when cold are plunged into warm water the colour of the skin changes to a deep violet—or as patients commonly express it, "turns black"—before the red stage appears, and sufferers from the disease learn to avoid this painful effect of too rapid warming of the chilled extremity The burning which follows the attack may persist for several hours, and may interfere with sleep at night

Attacks may appear suddenly in an individual previously healthy, though frequently there is a past history and family history of chilblains and dead fingers In two of the cases under our observation the onset was acute, an attack appearing for the first time accompanying severe post-partum hæmorrhage, and in another the attacks appeared after repeated severe chilling of the hands at work—washing up dishes and kitchen utensils in cold water at camp during the war—though the patient had never suffered previously from cold extremities

In most cases an attack may be produced quite easily by

placing the hands for a few minutes in water at a temperature of 15° C, and in certain individuals an emotional stimulus may be sufficient In one of our patients the sudden announcement that a stranger wished to examine her hands was sufficient to cause the fingers to turn pale and become cold, and another patient who was a professional singer noticed that frequently her hands became cold and numb just before the time came for her to appear on the concert platform

It is important to realize that although the attacks are transient, they may yet produce in time permanent changes in the tissues supplied by the bloodvessels involved The most obvious manifestation of such lack of nutrition is the molecular death of skin covering the terminal phalanges leading to ulceration, commonly referred to as whitlows, the ulcers breaking down repeatedly till their presence becomes continuous, at least during the colder months of the year

Another change which is seen from time to time is rarefaction of the bone of the terminal phalanges which occurs in association with stunting and "rounding off" of the fingers, so that the finger pad almost disappears (Fig 9) Since the bone at the base of the phalanx appears relatively healthy, it is probable that the rarefaction of the rest of the phalanx is due to sclerotic changes in the pad of the finger through which its blood supply has to pass, the epiphysis receiving its nourishment from branches given off before the digital vessels enter the pad

Mention of these sclerotic changes in the skin and subcutaneous tissues naturally leads us to the consideration of the stiffening and induration of the skin, a form of scleroderma which not infrequently occurs in Raynaud's disease The skin affection follows the characteristic distribution of Raynaud's disease, and is not widespread over the body surface as it is in true scleroderma The skin of the fingers and of the face becomes firm, loses its elasticity, and, as it is in reality shrunken and contracted, it appears stretched over

PLATE V

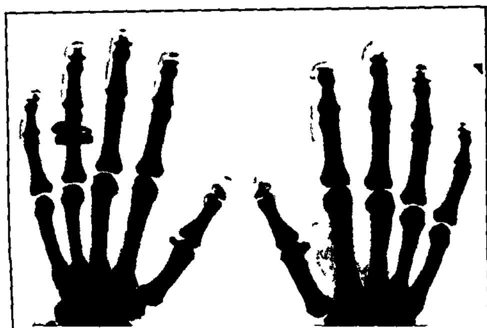


FIG 9.—SKIAGRAM OF FINGERS OF A PATIENT WITH RAYNAUD'S DISEASE, SHOWING THE DESTRUCTION OF THE TERMINAL PHALANGES

the bony prominences The shrinking round the mouth leads to contraction of the buccal orifice, the normal pliability of the lips being completely lost The skin is paler than normal, or slightly cyanotic, but after the operation of sympathectomy the natural colour returns, and the skin regains to a very great extent its natural softness and elasticity

Differential Diagnosis of Raynaud's Disease —The most advanced and extreme cases of Raynaud's disease in which trophic changes and even patches of gangrene occur have to be distinguished from other conditions which may lead to ulceration or gangrene of the fingers, especially syringomyelia and cervical rib These remarks apply, of course, to the affection as it appears in the upper extremity, in the legs the disease has to be differentiated from obliterative arteritis, which will be considered separately later

Syringomyelia can be identified by the characteristic dissociated anæsthesia, and by finding that when the sympathetic is affected the involvement takes the form of paralysis of the cervical sympathetic owing to disease in the cervical cord, and that there is complete absence of the vasospastic changes which might be associated with sympathetic overactivity

Certain cases of **cervical rib** in which circulatory phenomena are a prominent feature may simulate fairly closely the appearance of the fingers in advanced Raynaud's disease, but the two conditions can be readily distinguished because cases of cervical rib are unlikely to show the symmetry of Raynaud's disease in the hands, while the feet are unaffected The disturbance caused by a cervical rib, instead of coming on in attacks, is steadily progressive, leading eventually in certain instances to gangrene of the affected fingers Sensory signs may be present owing to pressure upon the lowest trunk of the brachial plexus, and the pulse, which is rarely altered in Raynaud's disease, may be greatly diminished or lost as a result of changes in posture, and finally permanently lost owing to sclerosis of the arterial coats [8]

It is probable that the interference with the blood flow to

the fingers may have a different causation in different cases of cervical rib, constriction of the subclavian artery between the scalenus anticus muscle and the fibrous band running from the rib possibly accounting for some cases, whereas others would certainly appear to be due to irritation of the sympathetic fibres passing over the rib in the lowest trunk of the brachial plexus [9, 10] Since the vascular phenomena may be due to stimulation of vasomotor nerves, the similarity to primary vasomotor disease is readily understood

Arteriosclerosis and Thromboangitis Obliterans—The importance of examining carefully for all the criteria of Raynaud's disease before considering the diagnosis as established may be appreciated by reviewing certain other conditions which may simulate the clinical picture Allen and Brown[11] have pointed out that cases of obliterative arterial disease may resemble closely those associated with vasomotor disturbances, and there is no doubt that arterial spasm may exist in association with organic arterial disease, this combination making the determination of the primary cause of the symptoms extremely difficult It is probably true that any organic disease of the vessels may produce vasomotor disturbances, and it has been assumed in explanation of the phenomena that the sclerotic process in the coats of the bloodvessel may act as the adequate stimulus for the production of a local vasoconstrictor reflex

The organic or obliterative diseases of the arteries which are most important in this connection are arteriosclerosis, both the simple senile and the diabetic forms, and thromboangitis obliterans In this group the clinical manifestations are observed in the lower more than in the upper extremities, and the colour changes are produced by alterations in posture, the toes becoming red when dependent and blanching when elevated Excessive fatigue after moderate exercise, and the pain of intermittent claudication are prominent features, and pulsation in the main vessels of the extremity is lost

In Raynaud's disease, on the other hand, all four extremities

may be involved, the colour being affected, not by posture, but by temperature or emotion Pain is associated with the variations in temperature and colour of the skin, and takes the form of burning and tingling, in distinction to the muscular cramps of the former group, and the arterial pulse is never lost

It has been estimated that 30 per cent of cases of thrombo-angitis obliterans show vasospastic features in the early stages of the disease, and it is in these, above all others, that difficulties will arise in diagnosis, for the clear-cut distinction between the organic and functional groups will not be present As regards suitability for operation, however, differentiation is of less importance, for these cases of thromboangitis with spasm which mimic an angeioneurosis are those which derive benefit from sympathectomy In these difficult cases the factor of sex may well be taken into consideration, for Raynaud's disease is a malady which attacks females almost exclusively, and it has been found that if cases diagnosed as Raynaud's disease in men be followed up, almost all of them finally develop the typical picture of obliterative arteritis, the mistake in the original diagnosis having been made during the early stage when spasm was present

The possibility that primary spasm of an artery may lead in the end to organic changes in its wall must also be borne in mind Telford and Stopford,[10] discussing the vascular complications of cervical rib, suggest that these are produced by the pressure of the rib upon the vasoconstrictor fibres in the lowest trunk of the brachial plexus, and further, that the spasm of the arteries must inevitably induce constriction or even obliteration of their vasa vasorum, with consequent nutritional changes in their walls leading ultimately to thrombosis Thoma's view of arteriosclerosis, which was critically discussed by Geoffrey Evans in his Goulstonian Lectures, may have some bearing on this subject He believed that arterial involution with final obliteration of the lumen might result merely from slowing of the blood stream through

a vessel, and although his view is not accepted as an explanation of the development of arteriosclerosis, it cannot be disregarded as a possible explanation of the commonly accepted belief that in the late stages of Raynaud's disease and other vasospastic conditions organic changes develop in the vessel walls

Skin Temperature Tests to determine the Nature of Arterial Obstruction—If the blood flow to the periphery be impeded by spasm of the arteries—whether the spasm be due to a central or to a peripheral mechanism is immaterial—once the spasm is overcome there will be a sudden surge of blood to the extremity, so that it will rapidly become warm If, on the other hand, the arteries are thickened, rigid and incapable of relaxing sufficiently to permit of a free blood flow, the rise in the temperature of the extremity will be gradual, and the affected limb may never reach the temperature of its healthy fellow In order to test this ability of the vessels to relax, which is, of course, a necessary preliminary to operation, the tests which depend upon inhibition or paralysis of the sympathetic are of extreme value Any or all of the procedures described at the beginning of this chapter may be employed, but we have come to depend for routine examination upon the reaction to warming the body for testing the vessels of the upper extremity, and upon the effect of spinal anæsthesia for testing the leg vessels

The typical response to warming the body in a case of Raynaud's disease is shown in the chart (Fig 10) Both hands had been cooled in a water bath at 15° C for twenty minutes, and after the hands had been dried and the thermocouples attached, the hot air chamber was closed and the lamps lighted The room temperature was 16° C It will be noticed that though the temperature of the hot air bath rose gradually to 35° C, the fingers of both hands remained about the same as that of the surrounding air It was only after about forty-five minutes, when the patient's body was very warm and she was sweating profusely, that the tempera-

ture of the fingers began to rise Until a few minutes before the temperature rose the fingers had been deeply cyanosed, but a red glow gradually replaced the blue colour, spreading from the bases of the fingers towards the tips, and shortly after the redness had extended to the thermocouple the temperature of that finger began to rise It seemed that the fingers were being warmed by the flow of warm blood from the palm which slowly made its way into the contracted digital

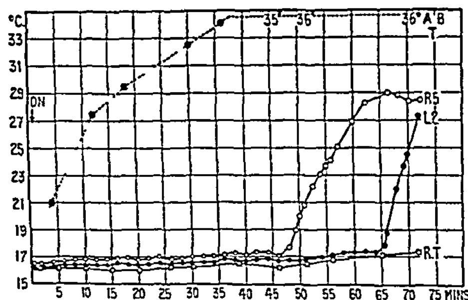


FIG 10—CHART OF SKIN TEMPERATURE OF FINGERS SHOWING EFFECT OF WARMING THE BODY (RAYNAUD'S DISEASE)

Time in minutes R5=temperature of right little finger, L2=temperature of left index finger dotted line A B T =temperature of hot air bath Note that the finger temperature remains low for a long period in spite of warming the body, and then rises rapidly

vessels It will be observed, further, that spasm in all the fingers was not released simultaneously, an interval of fifteen minutes occurring in this instance between the warming of the little finger of the right hand and the index finger of the left

The important point, however, indicating the spasmodic nature of the obstruction is the steep ascent of the temperature curve once the circulation became established—that is to say, that once the fingers began to warm up the full process of vasodilatation became complete in a very short space of

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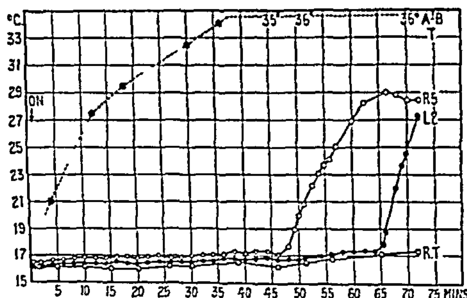


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Observations upon the temperature of the foot of a patient with normal arteries under spinal anæsthesia have been recorded already (Fig 8, p 31), and it now remains to describe the reaction when the arteries are obstructed by organic disease Fig 12 shows the chart of the temperature of the skin of the instep and the second toe in a case of syphilitic endarteritis obliterans, and the complete absence of any rise of temperature fifteen minutes after analgesia to the level of the seventh thoracic segment had been established provides conclusive evidence that the arteries are blocked by organic disease of their walls and that the element of spasm does not enter into the case at all This is an extreme instance, and is introduced to illustrate how definite the result of this test may be But many cases of organic disease, more especially of thromboangitis obliterans, will present a mixture of organic obstruction and spasm, the amount of spasm being indicated by the rise of temperature in the foot, and more particularly the rapidity with which this rise of temperature takes place The improvement in colour and temperature of the limb under spinal anæsthesia, which becomes established within ten minutes of administration of the anæsthetic, gives an accurate indication of the result which is to be expected from sympathectomy, and it thus becomes possible to select from a group of clinically similar cases of organic vascular disease

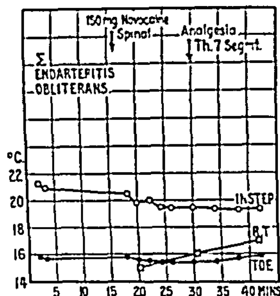


FIG 12 —CHART OF SKIN TEMPERATURE OF FOOT DURING SPINAL ANÆSTHESIA IN A CASE OF ORGANIC VASCULAR OBSTRUCTION DUE TO SYPHILITIC DISEASE, SHOWING NO RISE IN PERIPHERAL TEMPERATURE IN THE PRESENCE OF ANALGESIA

R T = room temperature Time in minutes (Compare Fig 8, p 31)

time The characteristic chart of a case of Raynaud's disease thus shows a long period of delay in which the fingers seem to be under the influence of the low room temperature, followed by a rapid rise of skin temperature, indicating release of spasm in the digital arteries

This chart is in marked contrast to that shown in Fig 11, which was prepared from a patient who had obliterative arteritis of the vessels of the left arm, no pulsation being perceptible in the vessels peripheral to the axillary artery The vessels in the right arm appeared to be normal, and examination of the chart will show that the temperature response in the fingers of the right hand is a normal reaction But the fingers of the left hand remained cold long after the heat had been turned on and after the vessels of the right hand were fully dilated, and then when the temperature did rise it rose very slowly, without any indication whatever of the sudden inrush of warm blood to the fingers which follows release of spasm It is the *shape* of the curve that is of the greatest importance, for the steeper the rise the greater is the spasm, and the flatter the curve the greater is the degree of organic obstruction

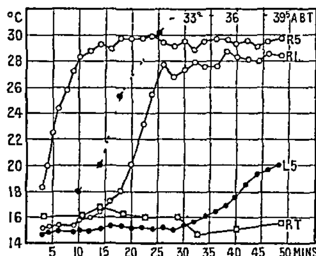


FIG 11 —CHART OF SKIN TEMPERATURE OF FINGERS, SHOWING EFFECT OF HEATING BODY (ORGANIC OBSTRUCTION OF VESSELS IN LEFT ARM)

R5 = skin temperature of right little finger, R1 = skin temperature of right thumb L5 = skin temperature of left little finger, dotted line A-B T = temperature of hot air bath, R T = room temperature Time in minutes The temperature of the left little finger rises gradually, in striking contrast to the rapid rise in the temperature of the normal side

great enthusiasm, and for divers pathological conditions At present the trend of surgical opinion in this country is opposed to it, owing largely to the inability of anatomists and physiologists to reconcile this procedure with the results of their researches, and it has become fashionable to say that the operation has no place in surgery There is no doubt, however, that in a certain small group of circulatory disorders the operation produces definite improvement, and it is foolish to refuse to recognize the improvement, and to refuse patients the benefit of the operation merely because there is no scientific basis on which to justify the procedure or to explain the results Herein lies a striking example of a clinical experience the secret of which has not yet been revealed by scientific investigation, if the misquotation may be forgiven, "Wisdom comes, but knowledge lingers"

The operation of periarterial neurectomy was designed on the assumption that the nerves to the peripheral vessels passed out entirely along the main branches of the aorta as offshoots and prolongations of the aortic plexus That this view is incorrect has been shown by many workers, the researches of Langley, of Todd and Kramer,[12] and of Woollard[13] being of special importance in this respect Todd and Kramer dissected out the nerves supplying the bloodvessels of the extremities and showed their origin from the peripheral nerves of the limb Woollard's conclusions were based on a series of excision and degeneration experiments on the hind limbs of cats, rabbits, rats, and guinea-pigs, but there is no reason to believe that there is any important difference between the arrangement of the vasomotor nerves in the lower animals and in man His work showed that the whole vascular tree from the aorta to the periphery was supplied with vasomotor nerves in two ways

From the adjacent ganglia of the sympathetic trunk large bundles of non-medullated nerve fibres pass into the tunica adventitia of the aorta, and, forming an interlacing plexus, they descend along the iliac arteries and can be traced as far as

those which will benefit from the operation and those in which sympathectomy would be futile

Sympathectomy to dilate Normal Arteries—Though attention has been focussed upon the conditions of impaired circulation and nutrition in which the bloodvessels are at fault, it must be remembered that the operation of sympathectomy has been performed with benefit for disorders in which the bloodvessels are healthy, but in which the improvement in circulation which results from removal of the constant vasoconstrictor tonus is of therapeutic value The cold blue limb of poliomyelitis, for example, is benefited by sympathectomy, not because there is overaction of the sympathetic, nor is there disease of the vessels, but because the physiological stimuli to the circulation which arise from normal muscular exercise are lacking, and sympathectomy, by paralyzing the vasoconstrictors, produces vasodilatation which in a normal limb is brought about by metabolites, though, of course, the operation cannot compensate completely for the absence of normal muscular action

In selecting such cases for operation the same tests may be employed to exclude organic vascular disease, a normal or even a delayed normal response of the Raynaud's disease type being the indication to proceed with the operation with good hope of producing definite improvement in the nutrition of the limb

2 Operations for Sympathetic Denervation of the Extremities

Periarterial Neurectomy—It is questionable whether this operation should be included under the heading of operations for sympathetic denervation, but it cannot be omitted from an account of the surgery of the sympathetic system because of its historical importance, and because of its definite, though now limited, therapeutic value

The lead given by Jaboulay was followed by Leriche, who since 1913 has repeatedly advocated the operation with

Blair, Duff and Bingham[14] examined a limb which was amputated a month after perivascular alcohol injection for diabetic gangrene Degenerated nerve fibres were found on the femoral artery close to the operation area, but on

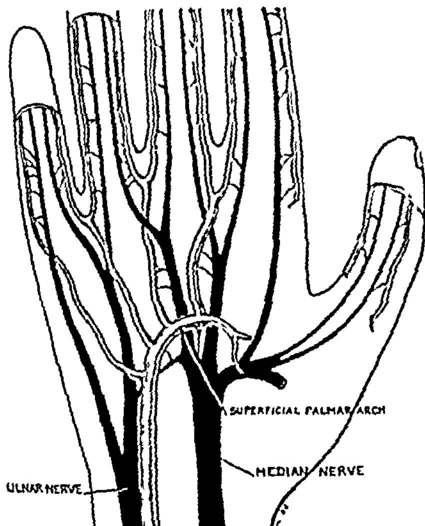


FIG 13 —DRAWING OF DISSECTION OF NERVES TO DIGITAL VESSELS
Note that ulnar distribution is confined to the arteries supplying the little finger and the ulnar side of the ring finger (Dissection by R E Norrish, Esq , F R C S)

the posterior tibial artery some only were degenerated, the majority being healthy The terminal branches of the blood-vessels had only healthy nerve fibres in their walls These observers emphasize their finding of an overlap on the posterior tibial artery where there were some degenerated

the femoral artery, where they gradually fade out These bundles give off individual fibres which pass into the tunica media, where they form a continuous fine meshwork

As this form of innervation comes to an end it is replaced by the second, which consists of tiny branches from the peripheral nerves which accompany the bloodvessels These branches become more numerous as the vessels are traced distally, and finally the arterioles are surrounded by interlacing fine terminal ramifications of nerve fibres The contributions from peripheral nerves are composed of medullated and non-medullated fibres, the non-medullated all being traceable to the nerve net in the tunica media It must be understood that by means of this nerve net continuity is established between the aortic outflow and the supply from the nerves of the limb, the elements composing the continuous ensheathing network all being postganglionic fibres of the sympathetic system It may be that the operation of periarterial neurectomy breaks the continuity of this network and produces a temporary and partial impairment of vasoconstriction, for there is no doubt that the operation is followed by obvious changes in the peripheral circulation, and, even in Woollard's experimental animals, periarterial neurectomy of the iliac artery of the cat was followed by vasodilatation visible in the paw for twenty-four hours

The evidence for the two sources of innervation of the limb vessels is not confined to animal experiment, but may be supplemented by several observations upon man By careful dissection minute branches of the peripheral nerves may be traced to the bloodvessels in relation to them Fig 13 is a drawing of such a dissection of the nerves to the digital arteries It should be noted that the ulnar nerve supplies the vessels on both sides of the little finger and on the ulnar side of the ring finger, the median nerve supplying all the other digital vessels This correspondence between the area of cutaneous sensory distribution and the vasomotor supply is constantly observed in the peripheral nerves

temperature of the limb is never anything approaching that produced by ganglionectomy, though both the changes in temperature and in the appearance of the skin seem to be of the same nature as those of radical sympathectomy on rather a small scale

This may be illustrated by the charts (Figs 14 and 15) prepared from a patient with normal bloodvessels who was

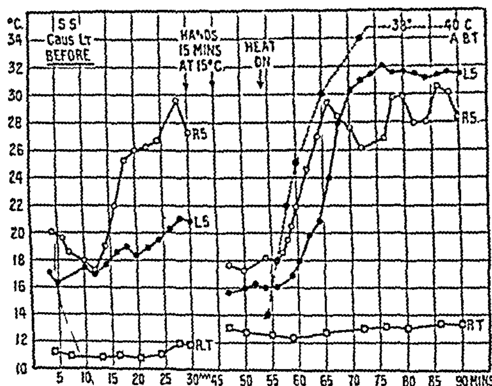


FIG 14—CHART OF SKIN TEMPERATURE OF FINGERS IN CAUSALGIA OF LEFT HAND BEFORE PERIARTERIAL NEURECTOMY

R5 = temperature of right little finger L5 = temperature of left little finger, R T = room temperature, dotted line A B T = temperature of hot air bath Time in minutes Note initial temperature lower on left side

suffering from causalgic pain in the left hand Fig 14, before operation, shows that in a cold room the temperature of the little finger of the left hand was constantly lower, and sometimes considerably lower, than that of the right little finger All the fingers of the left hand were slightly cyanotic and ached As the body was warmed in the hot air bath the fingers of the right hand heated up normally, and became

and some undegenerated fibres, and suggest that the absence of a clean line of demarcation between the proximal and distal nerve supply may be of importance in explaining the discrepancies in the results of the operation of perivascular neurectomy

In one of our cases Professor Woollard examined the arteries of a leg which was amputated 4 inches above the knee-joint five months after periarterial neurectomy had been performed on the common iliac artery There was no evidence of degeneration in any of the nerves accompanying the bloodvessels

As the sympathetic fibres accompanying the bloodvessels are believed to be entirely vasoconstrictor in function, the observations of Telford and Stopford[10] on three cases of cervical rib with vascular complications are important in this connection They contended that the impaired blood supply to the upper extremity in these cases was due to pressure of the cervical rib upon the vasomotor fibres entering the lowest trunk of the brachial plexus, and they noted that the arterial pulse could not be felt below an inch distal to the anterior axillary fold, though above this point the pulse was full and "thumping" They took this to mean that the portions of the arterial tree supplied from the ganglionated trunk, namely the subclavian and axillary arteries, were normal, whereas the vessels receiving their supply from vasomotor fibres distributed with the branches of the brachial plexus were in a state of constriction

The most obvious effect of a successful periarterial neurectomy is that the extremity feels warmer, and the arteries are evidently more dilated than before There is considerable variation, however, in the degree and the duration of this phenomenon, for in the lower animals it lasts only twenty-four to forty-eight hours, whereas in man it may be observed for about fourteen days, though it is probable that some less well marked change in the circulation persists for some weeks as judged by other criteria In its degree the change in

temperature of the limb is never anything approaching that produced by ganglionectomy, though both the changes in temperature and in the appearance of the skin seem to be of the same nature as those of radical sympathectomy on rather a small scale

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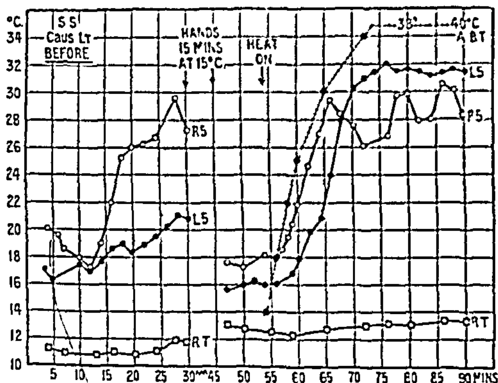


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pink and glowing The fingers of the left hand, after a slight delay, also warmed up with the normal steep curve, but became hotter and redder than those of the right hand, full vasodilatation being accompanied by burning pain which persisted throughout the following night

Fig 15, ten days after operation, shows that even in the cold room the little finger of the left hand was constantly warmer than the right little finger, its colour was pink, and

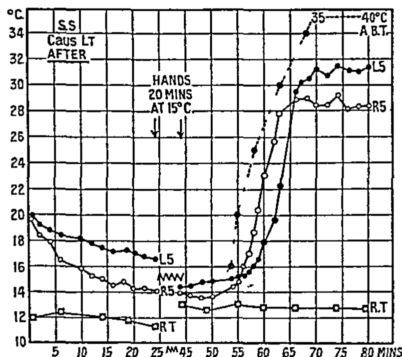


FIG 15 —CHART OF SKIN TEMPERATURE IN SAME CASE AS FIG 14 AFTER PERIARTERIAL NEURECTOMY

R5 = temperature of right little finger, L5 = temperature of left little finger R.T = room temperature dotted line A-B T = temperature of hot air bath Time in minutes Note initial temperature higher on left side.

it was painless After cooling both hands in water at 15° C for twenty minutes the little finger (and the other fingers) of the left hand was still a degree warmer than the right little finger, and when the fingers of both hands had reacted normally to warming the body, the fingers of the left, though warmer than the right, as before the operation, were pink,

and there was no burning pain. Similar reactions have been observed in other cases of periarterial neurectomy, and the conclusion to which they point is that the operation has produced a small but measurable amount of arterial dilatation, accompanied by constriction of the minute vessels, as shown by the colour of the skin before and after operation.

It is quite likely that the more thoroughly the artery is denervated the longer will the hyperæmia endure, and several cases have been recorded in which a considerable length of an artery has been completely excised and the limb on the affected side has remained markedly warmer than its fellow many months afterwards. This occurred in a case recorded by Babinski and Heitz after extirpation of an axillary aneurysm, and Halsted[15] published an account of a case of subclavian aneurysm treated by him which showed certain unexpected features which have an important bearing on this subject. The patient was a negro who had a large aneurysm of the second and third parts of the left subclavian artery. The vessel was ligated close to its origin, pulsation in the sac ceased, and it was noted that the left arm and hand became cold. The patient was then lost sight of for a time, but two years later, owing to a return of some pulsation in the sac, it was decided to excise the aneurysm. Before the operation the left arm was still the colder, but four hours after excision of the aneurysm the left hand and forearm were noted to be abnormally warm, and remained so for five weeks. When examined three months later, the temperature of the left arm varied from hour to hour and bore no constant relationship to that of the right side.

The difference between the effects of ligation and the effects of excision of a portion of the artery can be explained by assuming that vasoconstrictor impulses have been prevented from reaching the peripheral vessels in the case of excision. This observation of Halsted's fits in with the opinion of Lériche[16] on the subject of arterial injury and obliteration, though his explanation of the facts is that by resecting a

portion of the damaged artery one is removing a source of stimulation to the afferent side of a vasomotor reflex arc, the expression of whose efferent activity is seen in peripheral cyanosis, muscular contractures and trophic lesions in a cold extremity He believes that whenever the outer coat of an artery is injured, or when in the case of arterial obliteration by organization of a clot the inflammatory reaction reaches the outer coat, vasomotor phenomena in the limb are excited reflexly through the nerves in the tunica adventitia, and can be made to disappear entirely by resecting the obliterated portion of the vessel He cites experiences gained in the treatment of war wounds in support of his statements

The importance of knowing something of the behaviour of an artery after such an injury as ligation is at once apparent When Halsted's case and Leriche's work are studied it will be realized that the mere ligation of a vessel in its continuity may produce vasomotor changes in the periphery leading to impoverishment of nutrition of the tissues, whereas ligation of the vessel in two places and division between the ligatures may be followed by vasodilatation, warmth and other evidences of an adequate flow of blood to the extremity, especially in cases in which there has been a call for establishment of a collateral circulation before ligation of the artery was required This may explain why the well-recognized practice of double ligation and division is preferable to simple ligation in continuity

Lambert Rogers[17] has studied the duration of the effects after periarterial neurectomy both in animals and in man, finding that, although changes were noted only up to forty-eight hours in cats and rabbits, in man the period seemed to be about five weeks He took as his criterion the healing of chronic ulcers of the leg, and noted that the process of repair proceeded satisfactorily for about five weeks after operation If by this time the skin was healed it would be likely to remain so, but if the ulceration was still present,

healing ceased and the ulcer tended to increase in size again after that period had elapsed

It has been suggested in explanation of the effects of periarterial neurectomy that the operation interrupts afferent as well as efferent pathways There is plenty of evidence, histological, physiological and clinical, that afferent fibres pass from the bloodvessels into the central nervous system, though it is very doubtful how far they accompany the vessels before leaving them to join the spinal nerves It is supposed that the tonus of the muscle of the small arteries, like the tonus of voluntary muscle, may be under the control of a reflex arc having an afferent neuron from the vessel wall, a synapse in the spinal cord and an efferent neuron to the muscle coat of the artery The afferent neuron might be susceptible to stimulation by the tension within the vessel, and perhaps by other variants such as the temperature of the blood flowing through the vessel

Another suggestion is that the importance of the afferent fibres lies, not in their destruction, but in that they may actually be stimulated by the operation, the stimulus of the operative trauma being continued for some time afterwards by the reaction which takes place around absorbable suture material and effused blood, thus giving rise to peripheral vasodilatation by a form of axon reflex, or a Lovén reflex This seems to be the least acceptable explanation, for, carried to its logical conclusion, it would infer that the more the postoperative reaction the more prolonged would be the vasodilator effect It has already been mentioned that the best results are obtained by the most complete neurectomy—excision of a portion of the artery—and Lériche himself blames periarteritis for the very conditions, pain and trophic disturbances, which the operation is designed to relieve

This reference to pain introduces an aspect of the problem which is perhaps more difficult to understand than any of the others, though relief of pain is the most frequently noted beneficial effect of the operation It may easily be demon-

strated by arterial puncture that an artery is sensitive to pain, yet it is more than probable that the impulses pass to the central nervous system by the spinal nerves, passing for only a very short distance in the periarterial nerve sheath The pain of arterial puncture is abolished by rendering the whole limb analgesic by such an operation as section of the antero-lateral ascending tract in the spinal cord, but it is still present after all the sympathetic supply to the limb has been removed (see p 149)

But it must be remembered that direct injury to an artery is an abnormal form of stimulus, and the sensations proper to bloodvessels are probably produced by physical and chemical agents more frequently than by mechanical means Thus the pain which may be said to be of vascular origin is influenced by the temperature of the part, the posture of the limb, and therefore presumably by the pressure within the vessels and the tension on their walls, and also by muscular exercise, when metabolites, which accumulate owing to inadequate oxygen supply, provide the stimulus to the production of pain whose character is not the same as the acute pain of needle puncture, but is described as aching or burning, bursting or cramp-like Such is the pain of Raynaud's disease, of causalgia, of gangrene and of intermittent claudication, and the same kind of pain may be associated with chronic ulceration of the legs

It is pain of this nature which is benefited to a greater or lesser extent, and is often completely abolished, by periarterial neurectomy, and the remarkable thing is that, although the changes demonstrable in the periphery and attributable directly to improvement in the circulation are transient, relief of pain may be permanent Seeing that in a number of these conditions pain is the most serious feature as far as the patient is concerned, even though the local condition of the circulation may not be greatly affected, it is worth while performing this very simple operation in order to relieve the symptom

To relieve pain probably does much more for a sufferer than merely to alleviate his local condition, for the benefit which accrues to his body generally from the comfort, rest and sleep which he is subsequently able to enjoy may do more than we imagine in improving his metabolism and his powers of resistance and repair

The most striking instances of this occur in cases of senile gangrene, and especially in those in which there is dry gangrene of one or two toes, and no evidence, such as albuminuria, glycosuria or fever to indicate that the patient is suffering constitutionally to any great extent from the presence of the necrotic tissue The ideal treatment of such a condition is to await the gradual separation of the gangrenous toes by the natural but tedious process of the formation of granulation tissue, and finally healing by epithelialization of the end of the stump But the great objection to following this line of treatment is that the process is not only lengthy, it is also extremely painful, and the patient becomes worn out by loss of sleep and loss of appetite long before separation takes place Morphia, the most useful drug in the treatment of senile gangrene, may make the treatment possible, but often the pain becomes unbearable in spite of drug treatment, and amputation has to be considered It is at this stage that periarterial neurectomy ought to be carried out, for it may perhaps hasten the formation of the line of demarcation by improving the vascularity of the granulation tissue, but it will certainly relieve the pain, and the patient will be prepared to continue waiting for the natural process of cure to be completed At a later stage this process may be hastened by snipping through remaining strands of tissue when the separation is nearly complete, and provided this is done with the minimum of trauma, the tissues appear to tolerate the interference better than they do when neurectomy has not been performed

The following case is a good illustration of the value of the operation

The patient was a man, sixty-three years of age, who four weeks previously had developed dry gangrene of the left great toe

The left great toe was dark coloured, especially on the dorsal surface, but the ball of the toe was also becoming gangrenous The parts were dry and aseptic There was no pulsation in the dorsalis pedis or posterior tibial artery

Heart natural B P 160/90 mm mercury

Urine normal No other signs of disease

The patient was unable to walk owing to pain, and sleep was sometimes broken by pain

January 1, 1927 —Periarterial neurectomy of the left superficial femoral artery at the apex of Scarpa's triangle under novocaine infiltration anæsthesia, 2½ inches of the artery stripped of its tunica adventitia The artery was seen to be pulsating well, but plaques of degeneration were noticed in its wall

Result of Operation —Relief of pain, no circulatory change detected

Four weeks later gangrene was sharply limited to the terminal phalanx Six weeks after operation suppuration became more active at the line of demarcation, and granulation tissue with a good blood supply was seen to be forming, though the process was still very sluggish Ten weeks after operation the toe was amputated through the metatarso-phalangeal joint The stump healed slowly but satisfactorily, and the patient was able to walk bearing his full weight on the foot six months after operation He was examined again at the end of 1932 and was perfectly well, able to walk for long distances without discomfort, and having no trouble with the stump of the toe

Though healing was slow, the operation must be regarded as successful in that amputation of the leg was avoided

The remarks on the subject of senile gangrene apply also to diabetic gangrene, the pathology of which is essentially the same as far as the arteries are concerned

A retired Jewish baker, sixty-two years of age, who was suffering from diabetes mellitus, was referred to us because of a discoloured area on the dorsum of the left foot at the base of the third toe The diabetes was under control

Examination in May, 1931, showed a normal right foot, with a palpable pulse in the dorsalis pedis artery On the left side the pulse was not palpable, and there was a dusky red tender area 4 by 2 inches on the dorsum of the foot, the skin over this was broken and discharging blood-stained serous fluid from an ulcer 1½ inches in diameter

Treatment—The area was incised and drained on several occasions between May 29 and July 4, and at the end of September the lesion was still very indolent, the third toe was black, and a line of demarcation was forming slowly at its base There was severe pain which disturbed sleep every night

September 1, 1931—Periarterial neurectomy of the left common femoral artery under novocaine infiltration anæsthesia

Result of Operation—Immediate relief from pain, the patient being able to sleep all night without drugs

September 15, 1931—Amputation of gangrenous toe

October 2, 1931—The patient walked out of hospital, the wound being soundly healed and painless

He was examined again at the end of 1932, when he was walking naturally wearing ordinary boots, and had no complaints to make

No demonstrable improvement in the peripheral circulation, as tested by skin temperature, was ever observed, yet the improvement after the operation was most striking

It must be remembered that surface temperature depends largely upon the calibre of the small arteries, and it is possible that the blood flow may not be altered sufficiently to produce a demonstrable dilatation of the arteries, yet sufficiently to influence the circulation through the arterioles and capillaries, which are ultimately responsible for the nourishment of the tissues, and are probably capable of giving rise to sensations of pain if congestion takes place in them This is purely speculative, however, and it must be acknowledged that the relief of pain is something for which we must be duly thankful, but for which we have no satisfactory explanation

Technique of Periarterial Neurectomy—The operation may be performed under local anæsthesia The site of

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Technique of Periarterial Neurectomy—The operation may be performed under local anæsthesia The site of

operation is a matter of dispute, but if there is anything in the theory that success depends upon interrupting impulses *passing along the continuous nerve plexus, the more proximal* the site the better the result is likely to be, for as soon as large branches begin to leave the main vessel, portions of the plexus must accompany them, and so the more distal the neurectomy the greater will be the proportion of the total number of nerve fibres unaffected by the operation

The artery is exposed for a length of about 3 inches, and its sheath and the tunica adventitia are incised longitudinally for 2 inches As the artery is gradually peeled out of its outer coverings it may be gently retracted and rolled over, at first by an aneurysm needle and later by a piece of tape passed beneath it When the outer coverings have been stripped as completely as possible they are removed, and it must be remembered that as a large number of the nerve fibres are running on the inner aspect of the anatomical sheath, the only way to make certain of removing them is to remove the sheath as well as the tunica adventitia proper This may mean peeling off the sheath from the veins accompanying the artery

A small stream of normal saline solution is then allowed to trickle over the vessel, when further strands will become apparent floating in the fluid These must be removed, so that finally the middle coat looks smooth As this is being done the artery contracts down to a very small size, it becomes very pale or white in colour, and pulsation may cease beyond the area of operation This vasoconstriction is the constant response of an artery to trauma, and a good result cannot be expected to follow the operation unless this contraction of the vessel is seen

So as to ensure the complete destruction of all the nerve fibres in the tunica adventitia the vessel is then painted with 90 per cent alcohol, the excess is washed away with saline, and the wound closed

Sampson Handley has claimed greater success by injecting

alcohol into the tunica adventitia, but as the coat may usually be removed without difficulty or real danger, the necessity for an alternative method is not apparent

Results of Periarterial Neurectomy —When the statement is made that the operation of periarterial neurectomy is valueless, reference is usually being made to the application of this procedure to conditions which are by nature unsuitable for it For instance, it would be unwise to advocate this operation in the treatment of Raynaud's disease or thrombo-angitis obliterans, though occasionally an astonishing improvement may occur in the latter disease, the following case being an example

A Russian Jew, thirty-four years of age, by occupation a trunk maker, complained that for three years he had noticed pain in his right leg on standing While in bed both legs appeared normal, but as soon as he stood upright the right leg and foot gradually became cyanosed and painful This phenomenon became more and more frequent as time passed by, and the pain became so severe that he had to give up his work The change in the colour of the extremity was easily demonstrated in hospital by placing the leg in a dependent position

Examination of the rest of the body was negative

The urine was natural, and the Wassermann reaction negative

Arterial pulsation was present in the left foot, absent in the right

In July, 1924, periarterial neurectomy was performed under general anæsthesia, 1 inch of the right superficial femoral artery being stripped in Scarpa's triangle

Following the operation the right leg was palpably warmer than the left, and this clinical observation was confirmed by thermocouple readings The blueness of the leg and the pain disappeared completely, and he returned to work

He was examined at the end of 1932 He had been at work continuously since the operation, and had no symptoms in the right leg From time to time, however, he had noticed pain and discoloration of the skin of the left leg and foot, a condition similar to the right side before operation The

right foot was observed to be warmer than the left, and pulsation had returned in the right dorsalis pedis artery, the pulse in this vessel being better than that on the left side

The effect of operation in this case was almost miraculous, and one hesitates to attribute the improvement entirely to *its action* *It is well known that thromboangitis obliterans* is not always a steadily progressive condition, and also that spasm may be associated with the organic arterial changes in the early stages of the disease It is possible that the operation may have diminished spasm sufficiently to alleviate symptoms temporarily, but even if spasm be accepted as a causative factor in the disease, this operation can scarcely be considered an adequate prophylactic measure

(*a*) **Senile and Diabetic Gangrene** —Instances have already been quoted of the value of periarterial neurectomy in senile and diabetic gangrene It is practically impossible to foretell to what extent the operation will alleviate symptoms, but it is fair to say that when high amputation is the only alternative it is reasonable to give periarterial neurectomy a trial first The operation is a minor procedure which can be carried out under local anæsthesia without causing the patient any discomfort It may do good, and if it does not it will certainly have done no harm, and amputation can then be undertaken with the conviction that everything has been done to avoid it

We have performed the operation only four times for senile gangrene, but in every case the patient recovered with the loss of one or two toes There are many records of similar experiences, and some surgeons have published rather larger series Archibald Young[18] records ten cases, in all of which pain was relieved, and local amputation or low amputation became possible

Ralph Brooke[19] described five cases in which, in spite of advanced arterial degeneration, good effects followed periarterial neurectomy of the superficial femoral artery in Hunter's canal and ligation of the accompanying vein He noted particularly the raised temperature of the extremity, the loss

of pain, acceleration of the process of formation of a line of demarcation, and the sound healing which followed low amputations—in two cases he obtained satisfactory stumps after Syme's amputation

(*b*) **Intermittent Claudication** —Since Charcot's description, in 1856, of an old soldier who was not able to walk for more than a quarter of an hour without severe cramp in his legs, and who was found to be suffering from arterial obstruction, the condition has become familiar to the clinician, and is often seen in a more severe form than that present in Charcot's case It often happens that a patient may be unable to walk for more than 50 yards without getting cramp, and associated with this disability there are sensations of tingling and paræsthesiæ alternating with numbness, and congestion of the limb when dependent There is little doubt that intermittent claudication is produced by the products of metabolism which accumulate in the muscles because the blood supply is inadequate, and *it may be a premonitory symptom of* gangrene

There are records of a few cases of intermittent claudication which have been benefited by periarterial neurectomy One of our patients, a man aged fifty-four years, who was the subject of arterial degeneration, was able to walk only 50 yards without a halt After a rest of about two minutes he would be able to walk another 50 yards

Periarterial neurectomy of the common femoral artery was performed on both sides Six months later he was able to walk 2½ miles in an hour He still suffered from cramp if he hurried, but was able to walk considerable distances without stopping if he went slowly

That degree of improvement is the most that can be expected, and if the arterial disease be severe there may be no improvement at all We have observed some patients in whom two distinct kinds of pain were present There was the characteristic cramp-like pain of intermittent claudication felt in the muscles on exercise, and the aching and stabbing

pain characteristic of gangrene, felt in the feet, induced by the dependent position, and disturbing sleep After periarterial neurectomy the latter pain was relieved, while the pain of intermittent claudication persisted

Seeing that intermittent claudication is due to impairment of the blood supply to the muscles, the slight increase in the blood flow following *periarterial neurectomy can scarcely* be expected to be of appreciable value, and the condition really demands the fullest vasodilatation obtainable by radical sympathectomy The question whether the radical operation is justifiable may be answered by carrying out the tests which have been described already, for if inhibition or paralysis of the vasoconstrictor nerves provides a considerable increase in blood supply, then ganglionectomy, and not periarterial neurectomy, is indicated The obstruction to the arterial circulation may be due to senile or syphilitic lesions, or to *thromboangitis obliterans*, of which *intermittent* claudication is usually the earliest symptom The treatment of thromboangitis obliterans by sympathectomy will be considered in detail later (*vide* p 96)

(*c*) **Chronic Ulcers** —Acceleration of the healing of chronic ulcers as a result of periarterial neurectomy has been mentioned already, and there are numerous cases in the literature which illustrate the value of the operation in this respect The following is a typical example

A woman, fifty-eight years of age, had suffered from varicose veins for twenty-six years, and for one year there had been a varicose ulcer on the right leg which had proved refractory to conservative treatment, including rest in bed The varicose veins were bilateral and extensive, and there was an indolent ulcer an inch in diameter on the inner aspect of the right leg at the junction of the middle and lower thirds

Periarterial neurectomy was performed on the right superficial femoral artery in April, 1927 The ulcer was healed when the patient was discharged from hospital sixteen days later, and it has remained healed

It has been observed repeatedly that within a few days of the operation granulation tissue begins to replace fibrin on the surface of the ulcer, upon which bacteria are more rapidly destroyed owing to enhanced activity of phagocytes

Now that the treatment of varicose ulcers by the application of continuous firm pressure has been rediscovered, the need for periarterial neurectomy in these cases has ceased to exist But the operation may still be required for certain trophic ulcerations, and for perforating ulcer of the foot, though success is by no means constant, and many of the published accounts are either exaggerated or unduly optimistic Except in cases of very advanced vascular disease an initial improvement is to be expected, but unless this is sufficient to lead to the healing of the ulcer within four or five weeks the final result is likely to be a complete relapse

(*d*) **Leprosy** —Kenneth Black[20] has described his experience in ten cases of leprosy in which periarterial neurectomy brought about the healing of callous ulcers and unhealed stumps of spontaneous amputations Following this lead we operated upon a leper who was under the care of Professor Fraser

The patient was a postman, forty-five years of age, who for ten years had suffered from periodical ulceration of both feet He had already lost three toes from the right foot, and on the sole of the left foot there were two ulcers which refused to heal

In October, 1924, periarterial neurectomy of the left superficial femoral artery was performed, the ulcers healed rapidly, and the patient returned to his work as a postman Two years later, however, the foot became ulcerated again and the leg had to be amputated below the knee

The operation may be considered a partial success in that amputation was postponed for two years

(*e*) **Causalgia** —The value of periarterial neurectomy in the treatment of causalgia will be considered in a later section (*vide* p 153)

Sympathetic Ramisectomy and Ganglionectomy

The periarterial operation, though sometimes a useful therapeutic measure, is at best a poor kind of sympathectomy, and in order to obtain full vasodilatation it is essential to perform a radical sympathetic denervation of the extremity concerned In theory the best method of achieving this would be to cut all the grey rami running from the lateral sympathetic trunk into the limb plexus, for this would denervate the limb completely without interfering with the functions of the preganglionic fibres traversing the sympathetic trunk In the cervicothoracic region, for example, it would mean interruption of all the postganglionic fibres to the brachial plexus, and if only grey rami were divided, the preganglionic fibres running in the sympathetic trunk to the head, and the visceral branches to the heart and lungs, would be unaffected As regards the innervation of the lower extremity, the aim of a pure ramisectomy would be to deprive the leg of its sympathetic supply, leaving the visceral branches to the lower bowel and the pelvic viscera intact

In practice it is found impossible to achieve complete sympathetic denervation of the extremities by ramisectomy alone (Fig 16) The anatomical difficulty encountered in the search for the grey rami to the brachial plexus is well illustrated by the work of Sheehan,[21] and the unsatisfactory results of the operation of ramisectomy, even when performed by those most familiar with the technical problem have led to the development of other methods A large number of the grey rami supplying sympathetic fibres to the leg arise from the sacral ganglia deep in the pelvis, and here again complete ramisectomy presents insuperable anatomical difficulty

The next step taken in the attempt to make the sympathectomy more complete was to combine division of the grey rami with section of the sympathetic trunk, and this was proposed in the hope that the ganglia from which visceral

branches arise might remain, and perhaps be capable of independent activity even after the control exercised through the preganglionic fibres had been cut off In the cervicothoracic region the sympathetic trunk might be cut below the ✓second thoracic ganglion, and all the preganglionic fibres for the arm would thus be severed In the case of the leg, after cutting the grey rami passing into the second, third and

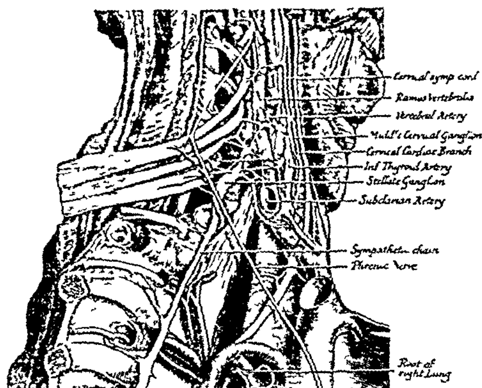


FIG 16—DISSECTION SHOWING THE CONNECTIONS OF THE LOWER CERVICAL SYMPATHETIC SYSTEM

The rami joining the roots of the brachial plexus vary in number and position, and many lie concealed among the fibres of the scalenus medius muscle Complete sympathetic denervation of the arm by ramisectomy is therefore impracticable

fourth lumbar nerve roots, the sympathetic trunk could be divided just above the pelvic brim, so cutting off the preganglionic supply for the sacral ganglia which supply postganglionic fibres to the rest of the leg and to the foot

This operation of ramisectomy and trunk section, though

it gave better results than ramisectomy alone, is open to criticism on two grounds Firstly, the trunk, if merely cut across, is capable of regeneration, and the effects may be short-lived for that reason Secondly, it is believed that peripheral vasodilatation is maximal only if the cells of the postganglionic fibres are removed

The only satisfactory method, therefore, of removing the sympathetic supply to a limb is by ganglionectomy, and the remarkable fact is that the results of the many operations which have now been carried out show that the loss of visceral branches of the ganglia has no appreciable ill-effect upon the patient It should be a rule of surgery to choose the operation which will achieve the desired objective without involving damage to other parts In this instance we are forced to break the rule, and it is providential that structures which have formerly been regarded as necessary for perfect function, if not essential to life, may be removed or divided without harm, and sometimes with great benefit to the patient

It is therefore the practice at present to remove the inferior cervical and the first and second thoracic ganglia to denervate the arm, and to remove the portion of the lumbar ganglionated trunk which supplies grey rami to the second, third and fourth lumbar nerves in order to denervate the leg This portion of the lumbar trunk is frequently referred to as the second, third and fourth lumbar ganglia The ganglia are so irregular, however, in the lumbar region that it may not be possible to identify these individual ganglia, and it therefore seems more correct to speak of the excision of a certain definite portion of the lumbar trunk supplying grey rami to the second, third and fourth lumbar nerves As a rule there are four lumbar ganglia, and as the fourth usually lies on the pelvic brim behind the common iliac vessels, it is not removed in the operation commonly practised for sympathetic denervation of the leg

Sympathetic Denervation of the Upper Extremity

Cervicothoracic Ganglionectomy—The object of this operation is the removal of the inferior cervical and the first and second thoracic ganglia At one time it was considered sufficient to excise the inferior cervical and first thoracic ganglia, which are usually fused into one mass, the stellate ganglion Kuntz showed that the second thoracic ganglion frequently makes a contribution to the sympathetic supply of the brachial plexus, either by sending a grey ramus direct to join the first thoracic nerve, or more commonly by supplying postganglionic fibres which run with a branch of the second thoracic nerve to join the first and thus enter the brachial plexus (Fig 2, p 6) The operation may be performed by a posterior or by an anterior approach

(1) **Posterior Approach**—The technique of the posterior approach to the inferior cervical and upper thoracic ganglia has been elaborated by Adson[4, 5] at the Mayo Clinic, and is at present that most frequently adopted in the exposure of these ganglia

The patient is placed in the prone position with the arms hanging down over the edges of the table The neck is flexed, the head being supported in a head rest of the type used for cerebellar operations Anæsthesia may be improved and the control of hæmorrhage facilitated by infiltrating the operation area down to the bones with a 0 5 per cent solution of novocaine containing adrenalin in a concentration of 1 in 200,000

The incision is made in the mid-line from the spine of the sixth cervical to the spine of the fourth thoracic vertebra, and the origins of the trapezius, rhomboids and serratus posticus superior are incised just to one side of the spinous processes These muscles being retracted laterally, the erector spinæ and the lower end of the splenius capitis are exposed It is necessary to identify the spines of the first and second thoracic vertebræ, and the erector spinæ must be

split longitudinally so as to lay bare their transverse process The first rib must then be exposed subperiosteally for 3 cms beyond its articulation with the transverse process of the first thoracic vertebra (Fig 17) The rib is divided at the outer end of the exposed portion, the transverse process is cut across where it joins the lamina, and the rib is again divided at its neck In performing these steps of the operation it is important to avoid damage to the pleura and to the first and second thoracic nerves and intercostal arteries

The pleura is then retracted gently from the lateral aspect of the vertebral bodies, and the thoracic trunk will be found close to the head of the rib, and anterior to the intercostal nerves (Fig 18) The trunk must be divided below the second thoracic ganglion, a portion of the second rib being removed, if necessary, to expose the trunk at this level The upper portion of the trunk is then drawn downwards so as to expose the first thoracic and inferior cervical ganglia, whose rami are severed one by one till the upper border of the inferior cervical ganglion is reached It is sometimes easier to resect the second rib as the first step, the resection of the first rib and the protection of the pleura being more readily accomplished after the posterior end of the second rib has been removed

All hæmorrhage having been controlled, the wound is closed in layers without drainage

A transverse section through the body shows that the thoracic sympathetic trunk lies much closer to the posterior surface, yet the approach from behind presents many difficulties The operation traverses very vascular muscles and involves the removal of portions of one, or more commonly two ribs on each side The trunk and its ganglia lie anterior to the thoracic nerves, and the upper part of the inferior cervical ganglion has to be drawn down for some distance from under cover of the first thoracic nerve, the complete removal of this ganglion presenting considerable difficulty to anyone not particularly familiar with the operation

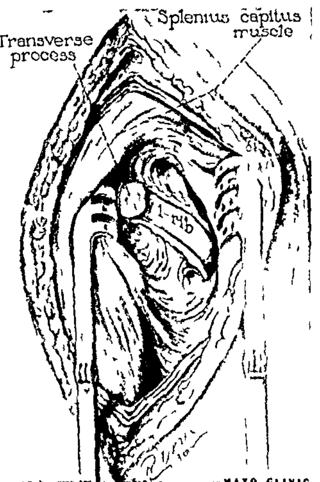


FIG 17.—CERVICOTHORACIC GANGLIONECTOMY BY POSTERIOR APPROACH EXPOSURE OF TRANSVERSE PROCESS OF FIRST THORACIC VERTEBRA AND FIRST RIB (ADSON)

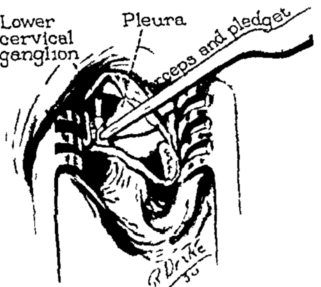


FIG 18.—CERVICOTHORACIC GANGLIONECTOMY BY POSTERIOR APPROACH EXPOSURE OF THORACIC TRUNK BELOW STELLATE GANGLION AFTER RESECTION OF POSTERIOR EXTREMITY OF FIRST RIB (ADSON)

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(ii) **Anterior Approach** — The anterior approach, in spite of the greater depth of the thoracic trunk from the surface, is a procedure which involves less damage to the tissues, gives a perfect exposure, and, if the anatomy of the part be

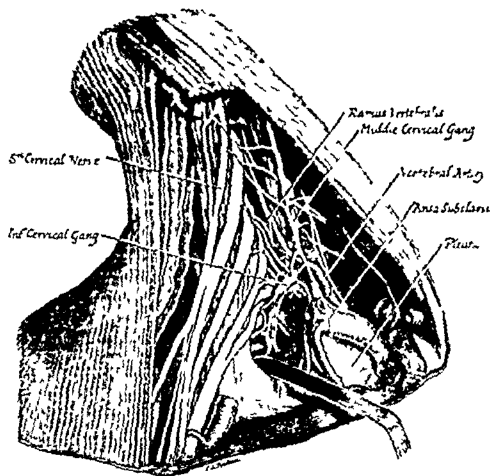


FIG 19 —DISSECTION TO SHOW RELATIONSHIP OF INFERIOR CERVICAL AND FIRST THORACIC (STELLATE) GANGLION, AND THE UPPER END OF THE THORACIC SYMPATHETIC TRUNK TO THE UPPER RIBS

Sibson's fascia has been divided and the pleura is being retracted so as to expose the stellate ganglion lying on the neck of the first rib, and the thoracic trunk running over the necks of the ribs below

studied carefully beforehand, will be found to present no difficulty (Fig 19)

The operation may be performed under general anæsthesia with nitrous oxide and oxygen, the tissues of the root of the neck being infiltrated with a 0 5 per cent solution of novocaine containing adrenalin 1 in 200,000

A low collar incision is made just above the clavicle, the external jugular vein is divided between ligatures, and the clavicular head of the sternomastoid muscle is incised till the internal jugular vein is just visible The posterior belly of the omohyoid muscle is defined and divided, and the scalenus anticus muscle is then exposed (Fig 20) Using a retractor with a narrow deep blade, the phrenic nerve is gently elevated and retracted inwards, and the scalenus anticus is cut through close to its insertion, thus exposing the second part of the subclavian artery It is important to make sure that none of the fibres of the deep part of the muscle or of its posterior sheath remain (Fig 21)

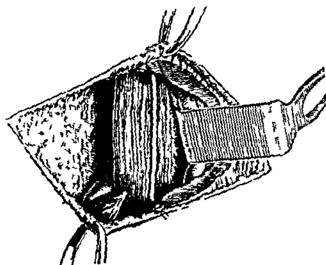


FIG 20—CERVICO THORACIC GANGLIONECTOMY BY ANTERIOR APPROACH

The omohyoid has been divided and the scalenus anticus, with the phrenic nerve lying upon it, is exposed

The subclavian artery is dissected so as to free its upper border and to define the origins of the thyroid axis and the vertebral arteries, the former vessel being divided between ligatures close to its origin It will now be possible to draw the subclavian artery downwards and forwards, and by incising Sibson's fascia along the inner border of the first rib the pleura is exposed By finger and gauze dissection the pleura is stripped gently from the first three ribs and the adjacent vertebral bodies, and is held forwards and outwards by a flat retractor of the spatula type (Fig 22) It must be realized that the exposure is limited above by the edge of the first rib, and nothing is gained by trying to retract upwards

In fact, great harm may be done if this retraction is attempted, because the lower roots of the brachial plexus are nipped between the retractor and the first rib

Using a headlight, the inferior cervical ganglion can be seen lying in its groove on the neck of the first rib, and the thoracic trunk can be followed down from it The trunk lies on the heads of the ribs, and where it crosses the head of the third rib it is hooked up, caught by light curved pressure forceps, and cut across below the second thoracic ganglion It sometimes happens that branches of the superior intercostal artery interfere with this step in the operation The simplest method of controlling them is by the use of Cushing's silver clips, but it is possible *to tie them in the* usual fashion

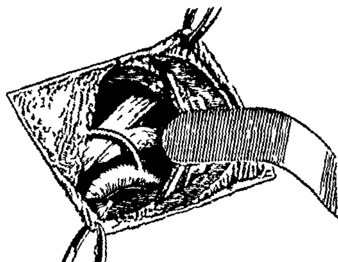


FIG 21—CERVICO THORACIC GANGLIONECTOMY BY ANTERIOR APPROACH

The phrenic nerve has been retracted inwards and the scalenus anticus muscle has been divided close to the first rib, exposing the second part of the subclavian artery and the lowest trunk of the brachial plexus Branches of the subclavian arising from the convexity of the exposed portion must be divided between ligatures

After the trunk has been cut across it is gradually freed in an upward direction, all rami passing to the first and second thoracic nerves being divided till the inferior cervical ganglion is reached The grey rami and the cardiac branches of this ganglion are divided one by one, starting inferiorly and working upwards to the top of the ganglion It may be necessary to hook the vertebral artery to one side in order to expose its upper limit, and though the dissection may be carried up the neck as far as may be desired, it is sufficient

A low collar incision is made just above the clavicle, the external jugular vein is divided between ligatures, and the clavicular head of the sternomastoid muscle is incised till the internal jugular vein is just visible The posterior belly of the omohyoid muscle is defined and divided, and the scalenus anticus muscle is then exposed (Fig 20) Using a retractor with a narrow deep blade, the phrenic nerve is gently elevated and retracted inwards, and the scalenus anticus is cut through close to its insertion, thus exposing the second part of the subclavian artery It is important to make sure that none of the fibres of the deep part of the muscle or of its posterior sheath remain (Fig 21)

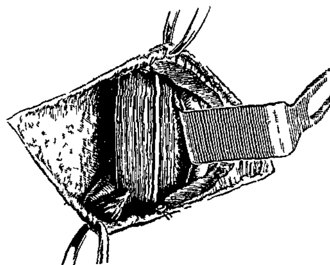


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PLATE VII

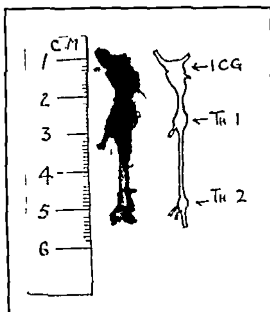


FIG 23.—THE INFERIOR CERVICAL GANGLION, THE FIRST THORACIC GANGLION FUSED WITH IT AND THE SECOND THORACIC GANGLION WITH THE INTERVENING PORTION OF THE SYMPATHETIC TRUNK, REMOVED BY THE ANTERIOR APPROACH

[To face page 70

for denervation of the arm if the cervical trunk be cut across just above the inferior cervical ganglion (Fig 23)

Though the amount of bleeding during the operation is very slight, it is well to insert a small piece of rubber to drain the cavity left in the upper part of the thorax so as to permit of the escape of blood which may ooze from small vessels after the effect of the local anæsthetic has passed off The sternomastoid, platysma and skin are then sutured, the drain being brought out at the outer extremity of the incision

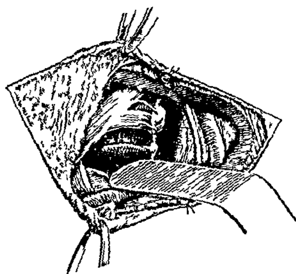


FIG 22 —CERVICO THORACIC GANGLIONECTOMY BY ANTERIOR APPROACH

The subclavian artery is being retracted downwards with the dome of the pleura after division of Sibson's fascia The posterior ends of the upper intercostal spaces are thus exposed and the sympathetic trunk is found close to the heads of the ribs The stellate ganglion lies upon the first thoracic nerve and the neck of the first rib

The drain is removed after twenty-four or forty-eight hours, the skin sutures on the third day, the patient is able to get up about the seventh day, and is usually able to go home on the tenth day after operation

There are important differences between this operation and those which have been introduced in recent years by Leriche and by Royle Leriche approaches the ganglion from the front, but removes only the middle cervical and stellate ganglia He makes no attempt to include the second thoracic ganglion, since he believes the removal of this ganglion to be a matter of no practical importance

Royle's anterior approach was planned to give access to the upper part of the thorax, so that the thoracic trunk might

be divided between the first and second ribs He exposed the trunk by feeling for it where it crosses the first intercostal space and hooking it up from the depths of the wound Having divided it and so severed almost all the preganglionic fibres for the upper extremity, he was content to leave the ganglion intact

The operation which we have described above was designed to overcome the incompleteness of the earlier ones, and the technique was worked out in collaboration with Professor Woollard in the Anatomical Department of St Bartholomew's Hospital

We have excised the inferior cervical together with the first and second thoracic ganglia by this method eighteen times On the third occasion the pleura was torn, but the resulting pneumothorax soon resolved, and the patient returned at a later date for the operation to be repeated on the opposite side, this time without accident Apart from this early misfortune, there have been no complications

On six occasions we have removed the ganglia on both sides at the same operation One of the patients was a lady of seventy-eight, and even at this age the procedure was well tolerated, recovery was rapid, and she was able to leave hospital nine days after the operation It is our impression that the more formidable posterior approach throws a greater strain upon the patient's vitality

It is frequently stated that cervico-thoracic ganglionectomy cannot be performed efficiently from the front The examination of the material removed at operation, and the subsequent physiological tests to determine the level of the sympathetic denervation, prove this charge to be without foundation

Sympathetic Denervation of the Lower Extremity

Lumbar Ganglionectomy—It has been explained already that the object of this operation is the removal of that portion of the lumbar ganglionated trunk which supplies grey rami

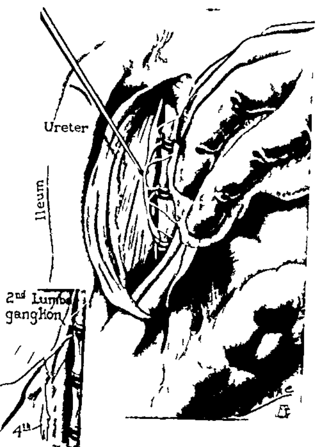


FIG 24.—TRANSPERITONEAL APPROACH TO RIGHT LUMBAR GANGLIONATED TRUNK (ADSON)

FIG 25.—TRANSPERITONEAL APPROACH TO LEFT LUMBAR GANGLIONATED TRUNK (ADSON)

[To face page 72

to the second, third and fourth lumbar nerves The operation may be carried out by the transperitoneal route from the front, or from the loin without opening the peritoneal cavity

(1) **Transperitoneal Approach**—When the lumbar trunk is to be excised on both sides the operation is commonly performed from the front [4]

The abdomen is opened by a left paramedian incision 6 inches long, two-thirds of the incision being below the level of the umbilicus The left lumbar trunk is approached by incising the peritoneum to the outer side of the descending and upper pelvic colon, mobilizing the colon and drawing it over to the right As the peritoneum is raised from the posterior abdominal wall all the vessels supplying the colon go with it, and so also does the ureter The dissection must be carried behind the peritoneum and over the surface of the psoas muscle until the inner border of this muscle and the bodies of the vertebræ are exposed (Fig 25) The lumbar trunk will be found lying upon the lateral aspect of the vertebral bodies just overlapped by the inner border of the psoas muscle, and it is traced up to the point at which it gives off the grey rami communicantes to the second lumbar nerve, at which point the second lumbar ganglion is likely to be placed It will be necessary to retract the duodenum upwards and forwards in order to expose the upper part of the lumbar trunk The trunk is divided just above the second lumbar ganglion, and is gradually freed in a downward direction, the rami which pass from it to the lumbar nerves and the visceral branches which run from it inwards towards the front of the aorta being divided one by one till the point is reached at which the trunk disappears behind the left common iliac artery Here the trunk is divided again, and the excision of the left side is thus completed The only structures which may obstruct the free exposure and removal of this part of the lumbar trunk are certain of the lumbar veins which may run superficial to it Any of them which run this course will require section between ligatures

All bleeding having been arrested, the colon is replaced and the peritoneum is repaired along its outer border

The right lumbar trunk may be exposed by incising the peritoneum to the outer side of the cæcum and ascending colon, mobilizing the colon and drawing it inwards in a fashion similar to that described for the left side An adequate exposure may be obtained, however, with less disturbance of the viscera, by packing off the small intestine upwards, and then incising the peritoneum just to the right side of the aorta (Fig 24) It is thus possible to work up behind the lower end of the root of the mesentery of the small intestine and the right colic artery, and to the inner side of the ureter, exposing the right side of the aorta, the inferior vena cava and the inner edge of the right psoas muscle In the upper part of the field the duodenum gets in the way and must be drawn gently upwards, but it is always a matter of difficulty to reach the second lumbar ganglion on the right side by this approach

The inferior vena cava must be drawn forwards and to the left, so as to expose the lateral aspect of the vertebral bodies, and the sympathetic trunk will be found close to the inner border of the psoas muscle Several lumbar veins will be seen crossing over the trunk, and great care must be taken not to damage these vessels when the vena cava is being manipulated, and when the trunk is being removed, those that pass superficial to the trunk must be tied and divided The trunk is then divided as high up as possible and freed in a downward direction, as on the left side, till it disappears behind the right common iliac vein, at which point it is divided again It may happen that the rami to the second lumbar nerve may escape division in this operation, but this omission is probably of minor importance, since the vasomotor fibres passing to the second lumbar nerves are unlikely to reach the leg and foot

The peritoneum of the posterior abdominal wall is repaired, and the abdomen is then closed in the usual way without drainage

the lumbar trunk as it lies on the lateral aspect of the vertebral bodies The lumbar veins are dealt with as described above, and the same care must be taken of the inferior vena cava on the right side

The advantage of the lumbar approach lies in the greater ease with which the upper part of the lumbar trunk is reached, and this is especially so on the right side, since the duodenum can easily be lifted forward in the course of the lumbar opera-

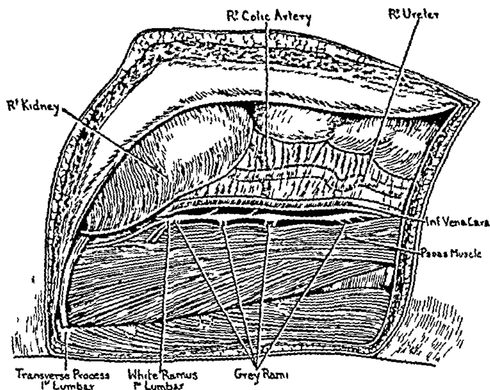


FIG 26—EXPOSURE OF RIGHT LUMBAR GANGLIONATED TRUNK FROM THE LOIN (ROYLE)

tion, whereas it can be retracted only with considerable difficulty when the trunk is exposed from the front

After exposure of the ganglionated trunk the operation is completed by removing the portion which extends from the level of the second lumbar vertebra to the brim of the true pelvis, and the muscle layers are then reconstituted Since so much muscle has been cut across and a large space has been opened up behind the peritoneum it will usually be well to drain the wound for twenty-four hours

(ii) **Approach from the Loin**—It sometimes happens—for example, in cases of poliomyelitis—that lumbar sympathectomy is indicated on one side only In such circumstances, and whenever for any reason a transperitoneal operation is inadvisable, the lumbar trunk may be exposed from the loin following the technique described by Royle

The patient is placed lying on the opposite side with a support under the lower ribs in order to open up the space between the last rib and the crest of the ilium on the side of the operation The position is very similar to that adopted for exposure of the kidney, but the pelvis should be tilted slightly towards the surgeon, who stands facing the patient's back

The incision is made parallel to the outer border of the erector spinæ muscle from a point half-way along the twelfth rib to the crest of the ilium, and then forwards along the crest to a point just behind the anterior superior spine This incision goes down to the muscle and a flap of skin and fascia is reflected forwards, exposing the lower attachment of the latissimus dorsi, and the external oblique muscle at its insertion into the iliac crest

Petit's triangle is defined, and the external and internal oblique and the transversalis muscles are then cut through close above the iliac crest, leaving just sufficient muscle attached to the bone to permit of accurate suture at the end of the operation The lumbar fascia is next incised in a vertical direction along the outer border of the quadratus lumborum, any fibres of the latissimus dorsi which obstruct the exposure being divided The abdominal muscles may then be retracted forwards, and when the fascia transversalis has been divided it is possible to strip the peritoneum forwards and inwards off the front of the quadratus lumborum and psoas muscles, displacing also the kidney, ureter and colon so as to get a good view of the inner border of the psoas muscle (Fig 26) A flat retractor may be needed, especially in the adult, to depress the inner edge of the muscle, so as to expose

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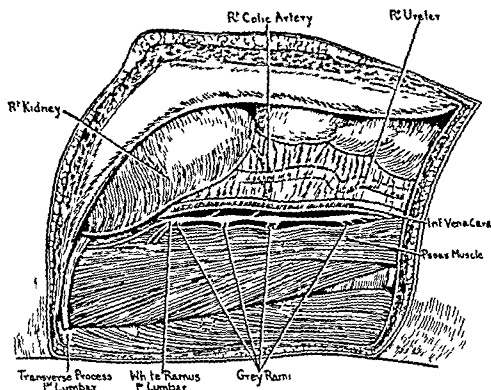


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It will be observed that the temperature of the right little finger was about 10° C higher than that of the left, the latter gradually cooling with exposure to the low room temperature After the hands had been removed from the water bath the temperature of the left little finger remained low, approximating still more closely to that of the room, whereas the temperature of the right little finger immediately rose rapidly to a point slightly above its original level

In this instance the body was not heated, and the chart illustrates merely the temperature change resulting from paralysis of the vasoconstrictor nerves supplying the arteries of the right hand

It was shown by Goltz and Freusberg as long ago as 1874 that in the course of time a moderate degree of tonus returns in vessels deprived of their vasoconstrictor nerves, and we have evidence that the results of their animal experiments hold good for man also One of our patients had cervicothoracic ganglionectomy performed for a form of arthritis affecting the right arm, the bloodvessels themselves being free from organic disease Shortly after the operation the temperature of the right hand was considerably raised, and the hand was not cooled by immersion in cold water But when she was examined again six months later it was noticed that the right hand was paler and cooler than the left, and it seemed to her that the temperature of this hand varied more with the external temperature than with the body temperature After cooling both hands to 15° C for twenty minutes the body was warmed up in the hot air bath, and the chart shows that whereas the left hand responded normally to warming the body, the temperature of the right hand remained low, approximating to that of the rather cold room (Fig 28)

It will be seen, therefore, that if after sympathectomy a considerable degree of tonus appears in the denervated vessels, the condition of the patient may be more precarious than it was before the operation, since the vessels are no longer under the control of the nervous mechanism It is

3 Effects of Cervicothoracic Ganglionectomy in Man

(1) **Bloodvessels—(*a*) Arteries**—The method of determining the state of activity of the sympathetic vasoconstrictor fibres by recording the skin temperature has been described already (p 27) The most striking effect of cervicothoracic sympathectomy is the rise of temperature in the fingers owing to dilatation of the small arteries as a consequence of interruption of vasoconstrictor impulses This is well illustrated by the accompanying chart (Fig 27), which records the temperature of the little fingers of both hands three months after cervicothoracic ganglionectomy on the right side The patient's bloodvessels were normal, and the operation had been undertaken for the relief of causalgic pain in the thumb and index finger Since the pain was associated with a disturbance of the vasomotor control in the affected fingers, the chart records only the temperature of the little finger, in which the bloodvessels were not involved in the causalgic phenomena

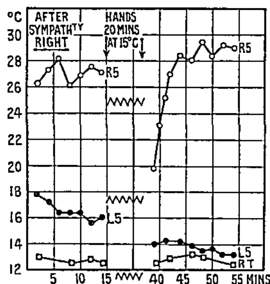


FIG 27—CHART OF SKIN TEMPERATURE OF LITTLE FINGER OF BOTH HANDS THREE MONTHS AFTER CERVICO THORACIC SYMPATHECTOMY ON RIGHT SIDE (NORMAL BLOOD VESSELS)

R5 = temperature of right little finger, L5 = temperature of left little finger R T = room temperature Time in minutes Note rapid rise in skin temperature on side of operation after prolonged cooling of both hands The body was not heated on this occasion

The chart is divided into two parts, the initial readings being taken before and the later readings after the hands had been immersed in water at 15° C for twenty minutes

(*b*) **Arterioles and Capillaries**—Whereas the arteries are controlled by vasomotor nerves, the minute vessels—that is to say, the arterioles and capillaries—though supplied by nerve filaments, are controlled by chemical bodies, the most important of which is commonly referred to as "H"-substance, the action of which is the same as that of acetylcholine and histamine Any tissue injury gives rise to the local production of "H"-substance, and Lewis[22] in 1927 brought forward experimental evidence to show that vasodilatation resulting from nervous impulses is due to liberation of "H"-substance at the nerve endings

Though the minute vessels may be accurately observed by capillaroscopy, the colour of the skin is a simple and reliable indicator of their condition In order to make accurate records of the colour of the skin a numbered range of colours should be kept as a standard, the skin colour being matched with the standard colours The following statement will act as a guide for interpreting the significance of alterations in the colour of the skin

If the skin is of a pink colour it means that the small arteries are dilated and the minute vessels are moderately open, should the latter become fully dilated, however, the colour changes to varying shades of red

When the skin is cyanosed, the small arteries are constricted and the minute vessels are dilated If the minute vessels become constricted also, the colour changes to white

The state of constriction of the arteries of the fingers influences their temperature, dilatation of the arteries producing a rise of temperature The colour of the skin depends upon the degree of constriction of the arterioles and capillaries It thus comes about that when the fingers are pink or red they are usually warm, whereas if they are blue or white they are cold

For the first forty-eight hours after cervicothoracic ganglionectomy the circulation in the extremity shows evidence of intense activity, the hand is hot and red, and the patient sometimes notices a bursting feeling in the limb Capillary

believed that vasomotor nerves exhibit the phenomena of reciprocal innervation, vasodilatation involving an inhibition of vasoconstrictor impulses If the vasoconstrictor nerves are destroyed, such inhibition of vasoconstriction cannot take place, and this may account, at least in part, for the late effects of sympathectomy now under discussion Lewis's investigations of patients after sympathectomy have led him to the conclusion that there are vasodilator fibres in the

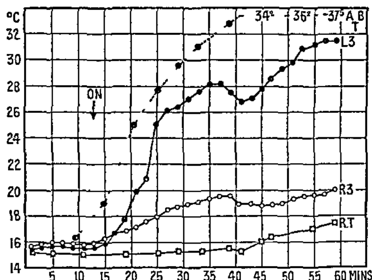


FIG 28—CHART OF SKIN TEMPERATURE OF FINGERS SIX MONTHS AFTER RIGHT CERVICO THORACIC SYMPATHECTOMY (NORMAL VESSELS)

L3 = temperature of left middle finger R3 = temperature of right middle finger, R T = room temperature dotted line A B T = temperature of hot air bath Note the more gradual rise on the side of operation during warming of body

sympathetic, and failure of a limb to warm up after operation may be due partly to blocking of vasodilator impulses

Cold can produce vasoconstriction reflexly through the vasoconstrictor nerves, but it can also do so by acting directly upon the vessels themselves The tonus acquired by denervated vessels may therefore be hastened in its onset and increased in intensity by cold This is in accord with our clinical observations, and is of great importance in connection with Raynaud's disease

tender, and amputation through the proximal phalanx was performed in March, 1930 Severe causalgia developed, involving the distribution of the outer branch of the median nerve, and he was unable to work In September, 1931, periarterial neurectomy of the right brachial artery gave partial and temporary relief, but six weeks later the condition was worse than ever, the skin of the thumb, thenar eminence and index finger was red and hot, and there were recurrent crops of herpetic vesicles on the pad of the index finger (Fig 29) By November, 1931, the constant irradiated pain in the distribution of the outer branch of the median nerve had become unbearable The affected area of skin was always redder than that of the rest of the hand, this red area being exquisitely tender to the lightest touch Cervicothoracic sympathectomy was therefore performed on the right side Two days after the operation the herpetic vesicles were disappearing, they had disappeared completely by the seventh day, and there has been no recurrence For the first forty-eight hours after operation the fingers were as red as they were before, but they then became, and have since remained, paler than the fingers of the other hand, and as pallor became established the hyperæsthesia disappeared

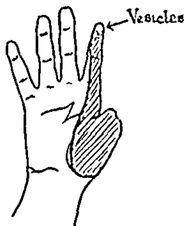


FIG 29 —DISTRIBUTION OF VASODILATATION AND HERPETIC VESICLES IN CAUSALGIA OF OUTER BRANCH OF MEDIAN NERVE

Vesicles disappeared, and vasodilatation of minute vessels was abolished after sympathectomy

It is of the greatest importance, therefore, to distinguish between the effects of sympathectomy as observed in the arteries and in the minute vessels Though both groups of vessels are dilated during the first forty-eight hours after operation, the minute vessels subsequently become and remain constricted Vasodilatation persists in the arteries, though in time the degree of dilatation diminishes as the tone of the arterial musculature increases

pulsation in the fingers is frequently observed During the same period the face is flushed, and the conjunctiva is congested on the affected side

This initial phase, characterized by paralytic dilatation of arteries and minute vessels, lasts for about three days, and then the conjunctival congestion disappears, the skin of the extremity becomes paler than that of its normal fellow, and pulsation is no longer observed in the minute vessels of the fingers This condition persists indefinitely, the skin of the arm and hand being warmer than before the operation because of dilatation of the arteries, but paler because of increase of the tone of the minute vessels

This surprising combination of heat and pallor following sympathectomy has been observed in animals as well as in man, and several suggestions have been offered in explanation of the phenomenon The explanation which appears most acceptable is that the increase in the blood flow through the arteries ensures the rapid removal of all products of tissue activity, including "H"-substance, and since it is "H"-substance which dilates the minute vessels, the washing away of this body results in constriction of the minute vessels and pallor of the skin It is interesting to note here that certain observations we have made of patients suffering from causalgia confirm these views

Causalgia is the result of irritation of a peripheral nerve, and vasodilatation is the most important element in the clinical picture On theoretical grounds Lewis suggested that all the manifestations of nerve irritation, including the formation of herpetic vesicles, and the appearance of trophic changes in the skin, would find their explanation in the local action of "H"-substance liberated by antidromic impulses The following case provides experimental evidence in support of this theory

V F, male, twenty-three years of age, a paper maker, lost the end of his right thumb in a machine accident in December, 1929 The stump healed in three weeks, but remained



FIG 30 —LEFT SIDE OF FACE AND NECK LEFT ARM AND SHOULDER AND CHEST ABOVE AND TO LEFT OF THE LINE COMPLETELY DRY REST OF BODY BATHED IN SWEAT AFTER EXERCISE

Photograph taken six months after left cervicothoracic ganglionectomy by anterior approach Horner s syndrome on left side

[To face page 8

(ii) **Secretion of Sweat**—To test the sweating mechanism it has been customary in the past, following the teaching of Horsley, to inject pilocarpine, and by examining for the absence of sweating to discover the extent of the denervated area It has been shown by Adson and Brown, as well as by Lewis, that pilocarpine can induce sweating in an area completely deprived of its sympathetic supply, presumably because the drug acts directly upon the sweat glands It is therefore fallacious to use this method as a test for sympathetic denervation

Sweating, which normally results from exercise or from heating the body, is produced reflexly, and is always absent in an area whose sympathetic supply has been severed from the centres of the spinal cord The line which separates the dry from the sweat-covered skin is an astonishingly sharp one, and is a reliable indicator of the extent of sympathetic denervation (Fig 30) If sweating is profuse, the droplets on the skin may be distinguished clearly enough to demarcate accurately the dry from the moist areas, but should there be any difficulty, cobalt blue papers may be used as indicators of the presence of sweat

The test does not differentiate between areas denervated by section of postganglionic as distinct from preganglionic fibres, since the whole area of skin whose preganglionic supply has been cut will be dry

Some of our patients have stated emphatically that the secretion of sweat has been considerably more profuse in the areas not affected by the operation At first we were inclined to regard this merely as an error of observation, the usual amount of sweat being considered excessive when contrasted with the completely dry denervated area However, the remark has been so frequently made, and it has been possible to observe the profuse secretion so often, that the possibility of compensatory hypersecretion cannot be excluded

(iii) **Pilomotor Mechanism**—The study of the activity of the pilomotor mechanism will sometimes yield information

which cannot be obtained from observations of sweating It is possible to determine the area of skin whose preganglionic supply has been cut, but under certain circumstances we may also be able to pick out in that area the parts which have been deprived of their postganglionic supply

Goose skin may be made to appear as the result of a reflex through the spinal cord, or as the response to peripheral stimulation If a block of ice be placed between the shoulder blades, goose skin appears over a wide area This depends on the integrity of a reflex arc with an afferent path to the cord in the spinal sensory nerves, and the efferent in the sympathetic nerves to the arrectores pilorum, and the reaction will not occur after section of any of the sympathetic nerves to the part, whether pre- or postganglionic After cervicothoracic sympathectomy the area over which this pilomotor response is absent corresponds to the area of skin which remains dry when the body is heated, and indicates the area deprived of its preganglionic supply

But goose skin may also be produced as a result of fairly powerful faradic stimulation of the skin The response is obtained more readily in some subjects than in others, and we have not used the test extensively because many patients find it distinctly unpleasant or even acutely painful Electrical stimulation will produce goose skin even though the preganglionic fibres corresponding to the part have been severed But if the ganglion cells be removed or the postganglionic fibres be cut, stimulation after the elapse of the period required for degeneration of the fibres will be ineffective This fact is important, because by means of this test the area of skin supplied from a given ganglion may be determined

(iv) **Muscular Power** —Though we have no observations of muscle tone to record, we have noticed that a constant sequela of sympathectomy is weakness of the voluntary muscles in the affected limb This loss of power may be shown by dynamometer readings, but it is quite obvious

observation for periods up to three years, and in none of them has restoration of function been complete, though no appreciable disability results It is stated that in the lower animals complete recovery of the eye eventually occurs, and this difference between man and the lower animals may be of importance, since it would appear that in man the intact excitor cells and postganglionic fibres cannot function perfectly when the preganglionic portion of the system has been destroyed

Effects of Lumbar Ganglionectomy — The effects of removal of a portion of the lateral sympathetic trunk in the lumbar region upon the bloodvessels, sweat glands and pilomotor mechanism of the lower extremity are similar to those described in the upper extremity after cervicothoracic ganglionectomy Seeing that the natural constrictor tone in the feet is greater than in the hands, the abolition of this tone by sympathectomy has a more marked effect upon the temperature of the feet than it has upon the temperature of the hands, but this difference in the extremities is one of degree only

4 Results of Sympathectomy for Disorders of the Circulation

Raynaud's Disease —Before attempting to assess the value of sympathectomy in the treatment of Raynaud's disease it is necessary to review the investigations which have been carried out to determine the nature of the malady

Raynaud, in his search for the explanation of the phenomena which later came to bear his name, first excluded all the well-recognized causes of arterial obstruction, and then focussed his attention upon the observations made by himself and others with regard to the effects of nerve lesions upon the blood supply and temperature of the parts to which the nerves were distributed He quoted cases published by Longet, Halter, Claude Bernard and Romberg to illustrate

without this test, for the patients have been unable for some days after the cervicothoracic operation to hold a cup while drinking, or to grasp an orange in order to peel it, and a feeling of weight in the arms and of dragging at the shoulders owing to weakening of the shoulder girdle muscles is a common complaint which is relieved by massage and disappears completely in a few weeks The explanation of this phenomenon is not clear, but it has been assumed that it is due to circulatory changes in the muscles, and certainly not to anything which causes permanent weakness

(v) **Oculomotor Phenomena** —In a brief but brilliant paper published in 1869, the Swiss ophthalmologist Friedrich Horner described a case showing ptosis, myosis, enophthalmos, and diminution of intraocular tension which he attributed to paralysis of the cervical sympathetic He also mentioned the dry, warm skin of the face on the affected side, his accurate studies of skin temperature being the first to be made in a clinical case (Fulton)

The preganglionic fibres to the eye may be interrupted by lesions of the brain stem or cervical cord, and by injury to the lower part of the brachial plexus They are always divided when the stellate ganglion is removed, but in some of our earlier operations, in which we merely divided the sympathetic trunk below the stellate ganglion, the eye fibres escaped injury, which shows that they pass out from the cord in the white ramus from the first thoracic segment

For the first few days after cervicothoracic ganglionectomy ptosis is very marked, the conjunctival vessels are engorged, and the tension in the eyeball falls to such an extent that accommodation may be impaired It has occasionally been necessary for patients who have previously worn glasses to have their lenses altered after the operation

By the end of a fortnight the ptosis is decidedly less marked than it was immediately after operation, and as time passes it may diminish still further, and the intraocular tension rises somewhat We have now had some of our patients under

by failure of the vis a tergo, whence the cyanosis and livid aspect which are seen in the majority of cases

"To attribute these phenomena to a fault of vasomotor innervation is an interpretation assuredly authorized by physiology I have further maintained that the marked symmetry of the lesions ought to suggest that they originate in a discharge either spontaneous or reflex, *starting from the* cord and radiating thence to the vascular nerves of the extremities In the present state of our knowledge local asphyxia of the extremities ought to be considered as a neurosis characterized by enormous exaggeration of the excito-motor energy of the grey parts of the spinal cord which control vasomotor innervation"

It is clear that Raynaud, on theoretical grounds, assumed that everything could be explained by supposing the sympathetic system to be in a state of great overactivity, the impulses conveyed by its efferent fibres producing spasm of the vessels and resultant changes in the extremity This view was accepted without criticism until the recent work of Lewis and his co-workers appeared, and even since Lewis's work was published Raynaud's opinion has been championed by Levy Simpson, Brown and Adson [23]

The calibre of the peripheral vessels may be diminished not only by vasoconstrictor impulses coming through the sympathetic nervous *system, but also by the direct effect of cold* upon the vessel walls Cold is also one of the stimuli which produce reflex vasoconstriction, and the problem is to determine the exact method whereby cold produces its obvious effect on the vessels in Raynaud's disease Lewis has brought forward convincing evidence, based on carefully-thought-out human experiments, to show that the fault lies not in the sympathetic system, but in the vessels The most convincing observations have been made when examining patients suffering from Raynaud's disease after the operation of sympathectomy has been performed The operation was advocated on the assumption that the sympathetic system

how section of sensory nerves, in animals and in man, may be associated with a fall in surface temperature, changes in the colour of the skin and even patches of gangrene He proceeded, however, to point out that in the malady under consideration there was no evidence of nerve injury , and also that, considering the numerous communications between the sympathetic and spinal nerves at their origin, even if a nerve lesion be allowed, it cannot be stated with certainty whether the results are due to a lesion of the spinal nerve or of sympathetic fibres running with it

This led him to a consideration of the experimental work published by Claude Bernard ten years earlier, and he wrote " The physiology of the circulation has been enriched by one of the most beautiful discoveries of the century In repeating the experiments of Pourfour du Petit on the section of the great sympathetic of the neck, M Bernard recognized that this lesion is accompanied always by a very notable elevation of temperature in the corresponding parts of the head Since then the doctrine of vasomotor nerves has passed from the domain of hypothesis to that of fact On the one hand anatomy demonstrated the existence of smooth muscular fibres in the middle coat of the arteries, on the other physiology established the subordination of these fibres to nervous influences " He thus came to postulate a spasm of the smaller bloodvessels, due to vasomotor influences, " occurring in subjects who are characterized by a nervous predominance," and he explained the distribution of the disease in the extremities by stating that it was the digits, the ears and the nose which radiate most heat from their surface, relative to their volume, and therefore cool most rapidly

Twelve years later, in 1874, in a supplementary account of later researches, he wrote " To the total closure of the arterial and venous vessels would correspond an exsanguine and cadaveric state of the extremities very analogous to that which is observed in frostbite, whilst the arterioles only being closed and the venules open one would see a venous stasis produced

unaccompanied by pain The effect of the operation has been to diminish the reaction to low temperatures, and not to remove the cause of the disease

These statements are illustrated by the chart (Fig 31) of finger temperatures taken fourteen days after cervicothoracic ganglionectomy for Raynaud's disease This chart is a typical example, all our other cases of Raynaud's disease having shown exactly the same reactions It will be observed

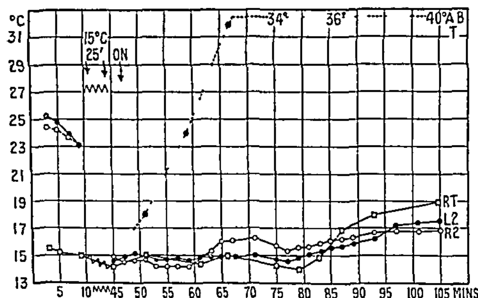


FIG 31—CHART OF SKIN TEMPERATURE OF FINGERS FOURTEEN DAYS AFTER BILATERAL CERVICOTHORACIC GANGLIONECTOMY FOR RAYNAUD'S DISEASE

L2=temperature of left index finger, R2=temperature of right index finger, R T =room temperature, dotted line A-B T =temperature of hot air bath Note initial high temperature of fingers, but later failure to warm up after cooling for twenty five minutes at 15° C, though the body was heated Time in minutes

that when the patient was first brought into the cool room her fingers were warm, their temperature tending to fall slowly Both hands were then placed in a bath of water at 15° C This procedure before operation had given intense pain, but the postoperative test gave no discomfort, though the fingers gradually became cyanosed After immersion in the bath for twenty minutes full cyanosis was established, and at the end of twenty-five minutes the hands were removed

was at fault, and it is interesting that the results of this treatment, though based on a fallacy, should be our most helpful guide in directing us towards the truth

Lewis's work cannot be described here in detail, but his method may be outlined and his conclusions summarized We have noted in our own patients that though immersion of the hands in water at 15° C causes the fingers to go blue, cooling the wrist by flannel dipped in cold water does not bring on an attack Lewis[24] went further and showed that if one finger were cooled, the others remaining warm, cyanosis appeared only in the cooled finger There is no vasomotor reflex known which would bring about this result, which must therefore be due to the direct effect of cold upon the vessels of the cooled finger

The effect of sympathectomy upon the bloodvessels of individuals not suffering from any disturbance of vasomotor mechanism has been described already If in Raynaud's disease the fault lav in the sympathetic system, an operation which blocks all the sympathetic impulses to the affected limb would be expected to produce in that limb a condition exactly similar to that of a limb with normal bloodvessels after sympathectomy The fact that in Raynaud's disease the vessels are still abnormal after sympathectomy seems to provide conclusive evidence that the abnormality does not lie in the sympathetic nervous system In addition, it may be mentioned that no pathological changes have been detected in the sympathetic ganglia excised

Immediately after the operation of cervicothoracic ganglionectomy, and for the succeeding few days while the patient is in bed, the behaviour of the hands in Raynaud's disease is identical with the normal But when the patient begins to move about again and is once more exposed to low temperatures it becomes clear that the susceptibility of the extremities to cold is still present, though more prolonged exposure is required to produce cyanosis, and the attacks, when produced are less intense than before operation, and may be

and rising rapidly at the time of the earliest readings The temperature of the hot air bath is not shown on the chart, because before operation vasodilatation commenced as soon as the body was warmed, and became complete before the temperature of the hot air bath had risen appreciably The room temperature was 16° C throughout both tests

Fig 33 shows the result of a similar test on a patient with Raynaud's disease, the only variation in the conditions being that the hands were cooled to 15° C for twenty minutes at the commencement of the test both before and after the operation On both occasions the room temperature was 15° C at the start, and was allowed to rise to 17° C by the end of the period of observation The sharp rise in the temperature of the fingers as the warm blood entered them before operation is in sharp contrast to the very gradual rise after the operation But the most marked contrast is between the curve after operation in Fig 32 and that after operation in Fig 33 In the case of the normal vessels the high skin temperature indicates paralytic dilatation of the digital arteries as a result of sympathectomy, whereas we believe that the low temperature in the case of Raynaud's disease indicates constriction of the digital arteries by the direct effect of cold upon their musculature Since this predominates over the vasodilatation which normally follows sympathectomy, the

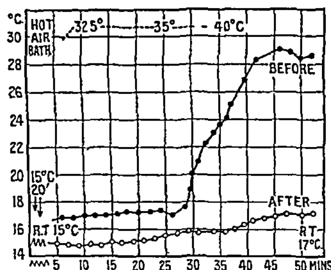


Fig 33 —Composite Chart from Same Finger of Patient with Raynaud's Disease before and after Cervico thoracic Ganglionectomy

Susceptibility of vessels to cold persists after complete sympathetic denervation

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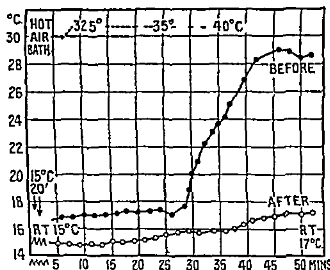


FIG 33 —COMPOSITE CHART FROM SAME FINGER OF PATIENT WITH RAYNAUD'S DISEASE BEFORE AND AFTER CERVICO THORACIC GANGLIONECTOMY

Susceptibility of vessels to cold persists after complete sympathetic denervation

from the bath, gently dried, and connected once more with the thermocouples The patient was then warmed up till her body was very hot and she was sweating profusely over the trunk and legs, the only dry areas being the head, neck and arms The hands exposed to the rather low atmospheric temperature remained cold and blue, and it is clear from the chart that the temperature of the fingers varies with the room temperature and not with the body temperature It was only when measures were taken to raise the room temperature that the finger temperatures rose, and even when this rise took place it was a very gradual process and quite unlike the sudden rise observed in Raynaud's disease before sympathectomy (*cf* Fig 10, p 39)

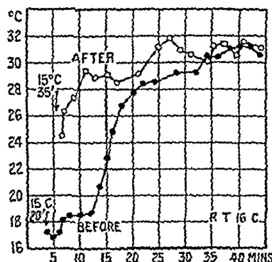


FIG 32 —COMPOSITE CHART FROM SAME FINGER OF A PATIENT WITH NORMAL VESSELS BEFORE AND AFTER CERVICO THORACIC GANGLIONECTOMY

After operation the effect of prolonged cooling of the hand passes off very rapidly

The difference between the effect of sympathectomy on a person with normal vessels and on one suffering from Raynaud's disease is well shown in Figs 32 and 33, which show the records of skin temperature under comparable conditions before and after sympathectomy Fig 32 is a composite chart of the finger temperature of a person with normal vessels before and after operation Before commencing the observations the hands were cooled in a water bath at 15° C, before operation for twenty minutes and after operation for thirty-five minutes, in the hope of lowering the finger temperature for an appreciable period It will be noted that after operation this was not possible, the temperature being high

operation, and the fingers are pink and warm If, then, the patient's hands are exposed to cold air or immersed in cold water, the more dilated arteries require more prolonged exposure to produce the degree of constriction brought about by slight exposure to cold before the operation This really means that sympathectomy enables the vessel lumen to remain open when exposed to a degree of cold which was previously sufficient to close it, and under the usual conditions of life the dilated vessels, though they still respond to cold, are not completely obliterated, and severe attacks are unlikely to occur Though the hands may become cold and mottled, the moderate degree of vasoconstriction is insufficient to cause aching pain

The burning pain which is so troublesome at the end of an attack is associated with rapid vasodilatation, which is usually brought about by the patient warming up the hands too quickly As this rapid vasodilatation does not take place after sympathectomy this particular form of pain, which is often severe enough to interfere with sleep before operation, is abolished

It thus comes about that a housewife who has been unable to make a bed without stopping in the middle to warm her hands after handling the cold sheets, and to whom it had been intolerable agony to hang wet clothes out to dry, is enabled by the operation to perform all her household duties without discomfort Such is the experience of 8 out of the 10 patients upon whom we have performed ganglionectomy for Raynaud's disease, the remaining 2 showing some improvement, but still suffering pain when exposed to only moderately low temperatures The result in one patient whose rami were cut was unsatisfactory, probably because the operation was incomplete

In the course of time the calibre of the vessels under optimum conditions becomes smaller owing to recovery of intrinsic tone, and when this tone has been established it requires less cold to produce cyanosis It is therefore im-

conclusion that Raynaud's disease is primarily an affection of the vessel wall appears to be inevitable

The recovery of tone in normal vessels deprived of their vasoconstrictor nerve supply has been referred to, and the response of the digital vessels to cold in Raynaud's disease after sympathectomy suggests the presence of this inherent vascular tone in an exaggerated form, intensified by the stimulus of cold This increase in tone may explain the persistently low temperature of the fingers after cooling, but other suggestions have been made to explain the loss of the sudden vasodilator response which is observed, if the body is warmed for a sufficient length of time, in untreated Raynaud's disease

After the sympathetic supply has been cut off, sudden alterations in the calibre of the peripheral arteries cannot occur All the circulatory changes are more gradual, and are influenced by external stimuli rather than by controlling mechanisms within the body That the sluggish character of these responses is the result of isolating the vessels from their nervous control is undoubted, and it has been supposed that the loss of the vasodilator response after sympathectomy shows that there are vasodilator fibres in the sympathetic, though proof of the presence of such fibres is lacking It is more likely that whenever vasodilatation takes place the process is accompanied by inhibition of vasoconstrictor tone, and that after sympathectomy this inhibition cannot occur

The effect of sympathectomy in Raynaud's disease may be summarized by saying that the operation is palliative, alleviating pain, promoting the healing of ulcers and preventing their recurrence, and diminishing the intensity of the cyanotic attacks It will be remembered that the pain is of two varieties, aching when the fingers are cold and blue, and burning when the fingers are red and hot at the end of an attack After sympathectomy, so long as the hands are exposed to a moderately warm atmosphere the arteries are more dilated than they were under similar conditions before

the vessels It is not to be supposed that there is uniformity in the sympathetic system, and individual variations in the susceptibility of the sympathetic system to stimulation—for instance, by fear—are well recognized Given an individual whose bloodvessels are unduly susceptible to the action of cold, it is not difficult to imagine that the added effect of a sudden emotional stimulus might overbalance such a person into an attack, though the sympathetic system itself is normal within the limits of individual variation The result of operation in the patients who showed this reaction to emotion was precisely the same as in the other cases of Raynaud's disease, the susceptibility of the peripheral vessels to cold persisting after sympathectomy

When ganglionectomy affords only moderate relief, it is sometimes assumed that there must have been some technical error and that the operation has been incomplete We have examined our patients very carefully to make sure that the whole of the extremity has been deprived of its sympathetic supply, yet in the presence of full evidence of complete sympathectomy cyanosis may still be produced

Attention has been concentrated upon the hands, for in some cases the feet may be scarcely affected, and when they are involved they do not suffer as severely as the hands It is a common experience, also, that the results of lumbar ganglionectomy for Raynaud's disease are better than those of cervicothoracic ganglionectomy, and some have supposed that this indicates that the lumbar operation is the more radical, some of the sympathetic supply still reaching the hand after removal of the inferior cervical and the first and second thoracic ganglia It has just been stated that all the evidences of sympathetic denervation are present in the hand after this operation, and there is another reason for the better result in the foot which is the true explanation of the difference between the upper and the lower extremity

If the vasoconstrictor nerves to the extremities be paralyzed by local anæsthesia, the resultant rise in the temperature of

possible to make a true estimate of the result until the patient has passed through the second winter after the operation Of our 10 patients, 6 have passed through this critical period, and 4 of these are well satisfied with the result Though their fingers still go blue at times, they are able to carry on with their work without discomfort The other 2 suffer severely in cold weather, and though both these patients showed considerable improvement for six to nine months, their hands are now as bad as they were before operation It is interesting and important to note that in both these patients there had been severe ulceration and other "trophic" defects when they were first seen One had scleroderma and destruction of bone in the terminal phalanges of all her fingers, and the other had superadded organic obliterative disease in arteries as large as the radial It is therefore clear that the best results will be obtained in the early cases, before spasm is complicated by organic changes in the vessel walls

4 of our patients were operated upon during last winter, 3 with a good and 1 with a fair immediate result

There is still one argument brought forward by the supporters of the vasomotor neurosis theory of Raynaud's disease which remains to be answered The fingers of some patients become cold and blanched not only on exposure to cold, but also as a result of an emotional stimulus One of our patients who was a professional singer complained that her hands became cold shortly before she had to appear on the stage, and in another an attack always occurred if she was examined by somebody whom she had not met before Those who believe that the malady is a disease of the vasomotor nerves consider the precipitation of an attack by an emotional stimulus to be a strong point in favour of overaction of a central sympathetic mechanism

There is an alternative explanation, however, depending on the fact that the local application of cold and central stimulation of the vasoconstrictor nerves have the same effect on

of patients suffering from thromboangitis obliterans, and have formulated the theory that the fundamental cause of the disease is hyperactivity of the suprarenal glands

Telford and Stopford[5] have drawn attention to the distribution of the vascular lesions, and point out that there are features which seem to be common to these lesions and the vascular lesions in certain cases of cervical rib The latter are believed to be the sequelæ of stimulation of vasoconstrictor nerve fibres, and these observers have therefore put forward the suggestion that in thromboangitis obliterans also vasospasm may be the initial lesion, which in time induces thrombosis by interfering with the blood supply of the vessel wall

In so far as the clinical picture can be a guide it certainly seems that it may be possible in time to divide cases of this disease into groups according to their degree of spasmodic, as distinct from organic closure, for in a considerable proportion of the early cases changes in the peripheral circulation come and go in a fashion that appears to be incompatible with an obliterative arteritis

This reference to the theories regarding the causation of thromboangitis obliterans is made at this point because of the important bearing which such considerations have upon surgical treatment Those who consider the disease to be an obliterative arteritis from the start can find small justification for sympathectomy, the only hope of improvement lying in the possibility that the operation may bring about an improvement in the collateral circulation by producing vasodilatation in vessels not as yet involved in the disease Those, on the other hand, who believe that spasm plays a part in the ætiology advocate sympathectomy in the earliest stages of the disease in the hope of arresting its progress

At the present time we do not know enough about the pathology of thromboangitis obliterans to decide which of these views is correct, but the problem is one in which clinical research is likely to prove of extreme value If a

the digits is greater in the foot than in the hand This simple experiment shows that the natural vasoconstrictor tone is greater in the lower than in the upper extremity, and the permanent removal of this tone by sympathectomy will therefore have a more striking effect in the foot than in the hand In addition, the fact that the feet are usually covered, whereas the hands are often bare when exposed to cold, has an important bearing upon the results in Raynaud's disease Actually, cervicothoracic sympathectomy is a more radical procedure than the lumbar operation, for in the former the ganglion cells supplying the hand are removed, whereas the lumbar operation consists mainly of excision of the preganglionic fibres for the foot, the sacral ganglia which contain most of the ganglion cells for the foot being left intact

Thromboangitis Obliterans —Though the primary cause of thromboangitis obliterans is a matter for speculation, there is no doubt that the condition is characterized by progressive deterioration of the arterial walls which ultimately leads to occlusion of the vessels and gangrene of the limb It is a matter of experience that about 25 per cent of those afflicted by the disease require amputation within five years from the onset of symptoms It is thought, however, that spasm is frequently associated with organic vascular disease, and it may be that the association is sometimes one of cause and effect

Buerger believed that even in the earliest stages of the disease inflammatory lesions are present, and that as these lesions heal the characteristic and specific morphological picture makes its appearance He gave it as his opinion that the manifestations of the disease in its acute stages suggest the presence of bacterial infection as the causative factor, but he was unable to demonstrate any organism, though other workers have isolated a bacillus from the lesions and from the blood stream which they believe to be the pathogenic agent

Oppel and others, however, believe that they have discovered an excess of vasoconstrictor substances in the blood

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series of patients be taken, and in every case the history be carefully analyzed, and the capacity for vasodilatation be determined by spinal anæsthesia *before operation, and if the* result of operation be followed up for a period of five years, the correlation of the "follow-up" and the preoperative data should provide information not only about the value of sympathectomy, but also about the nature of the disease A longer period of observation *may prove to be necessary,* because it is well recognized that the progress of the disease may be arrested for some months, or even years, without treatment, but seeing that if untreated the disease so frequently produces gangrene within five years of its onset, the effect of the operation upon its progress is likely to be known by the end of the five-year period

Such a series of observations is being made by Telford and Stopford For the preoperative surface temperature observations they choose the thin skin over the instep, the temperature of which rises 8° to 10° C in a normal individual under spinal anæsthesia In one of their patients, a man forty-one years of age, the rise of temperature was 6 4° C in the right foot and 5 8° C in the left The result of sympathectomy was entirely satisfactory and the patient returned to work In another, a man fifty-nine years of age, the rise was 1 6° C in the right foot and 0 9° C in the left The result of sympathectomy was some improvement in the right leg, but the left had to be amputated for gangrene two months afterwards These cases are quoted as typical examples of the experiences described by these observers, whose results (1933) may be summarized by saying that, of their 16 patients, 9 are free from pain and able to walk well, 3 showed relief of pain but little increase in working capacity, and 4 showed no improvement or required amputation

The return of pulsation in vessels in which the pulse has been absent before operation is not to be expected, since such vessels are completely obliterated by organized clot,

and the beneficial effects of the operation must be due to dilatation of unobliterated vessels The earlier in the disease and the younger the patient, the better will be the result of sympathectomy, for the fibrotic changes in the vessels due to the disease and to advancing years will then be minimal

Our own experience is much less extensive and less fortunate than that of Telford and Stopford

Our first patient was a man thirty-one years of age, born in Dundee of Scottish parentage The disease appeared in July, 1929, as an onychia of the left little toe-nail, and progressed steadily till his left leg had to be amputated above the knee in November, 1930 In December, 1930, he complained of burning pain in the toes of the right foot exactly similar to the pain he had experienced on the left side Examination in February, 1931, revealed a cold blue clammy right foot, with no pulsation in the dorsalis pedis or posterior tibial arteries

Lumbar ganglionectomy was performed on the right side on February 17, 1931, and although after the operation the pain in the foot was relieved and the temperature of the extremity rose several degrees, the pain returned in May, gangrene of the toes appeared in June, and on July 15 the right leg had to be amputated

The arteries of the amputated leg were injected by Professor Woollard with barium emulsion, and skiagrams showed obliteration of the arterial supply to the toes, and extreme narrowing of all the vessels below the popliteal Histological examination showed such advanced vascular disease that the reason for the failure of sympathectomy was obvious

This was an instance of the disease in its most virulent form, and perhaps we ought not to have been as discouraged by the result of operation as we were But we did not attempt to treat any other patients until 1933, and these cases are too recent to use as evidence of the value of the operation, though we have reason to believe that it may be of real value in the treatment of properly selected cases of the disease Even in these, however, disappointments sometimes

occur simply because of the nature of the disease with which we have to deal

One of our patients, a man aged forty-five, came to us because of claudication after walking less than a hundred yards, and of severe pain in the feet even when at rest in bed However, the pulses were palpable in both dorsalis pedis arteries and in the right posterior tibial artery, and under spinal anæsthesia the temperature of the toes rose from 20° to 31° C, and of the insteps from 23° to 30° C, the colour of the skin improved to a remarkable degree, and the pulses became stronger It was noted that though all temperatures rose to an equal extent, the readings on the left side were all about 1° C higher than on the right Bilateral lumbar ganglionectomy was therefore performed with a most gratifying immediate result, and the patient walked out of hospital three weeks after the operation in comfort When he had been at home for one week he experienced a sudden pain in the left leg and foot, and within a few minutes the foot became cyanosed and cold He returned for examination five weeks after operation and presented a very striking clinical picture The right foot and leg were pink and warm and comfortable, just as they had been ever since the operation had been performed, but the left foot and the distal half of the leg were cold and cyanosed, and no pulsation could be detected in any of the vessels He complained of great pain in the left foot, and it was clear that in spite of sympathectomy the disease in the left leg had progressed to complete obliteration of one of the main vessels, probably the posterior tibial artery

Such complications are inevitable without operation, and their occurrence in the apparently favourable cases after operation should not deter us from offering patients surgical treatment, which would appear at present to afford the best chance of hindering the progress of the disease, and of delaying the appearance of its complications It sometimes happens, too, that even when the demonstrable improvement in the circulation and function of the limb appears trivial, the patient may obtain relief from the pain which had previously been experienced while at rest

Adson[20] stresses the importance of a course of medical treatment prior to operation if the disease shows signs of activity He holds that surgery is contra-indicated if arterial thrombosis is extending, and unless the disease is already quiescent, treatment with rest, warmth, baths, hypertonic saline, and foreign protein is to be carried out for a period of at least four to six weeks, or for as long as is necessary for ulcers to heal and for gangrene to become demarcated Out of 240 cases at the Mayo Clinic, 150 received medical treatment and 90 were operated upon Figures are published to show that—

Of untreated cases, 25 per cent require amputation,
Of those treated medically, 14 per cent require amputation,

and

Of those treated surgically, 5 per cent require amputation

It is to be presumed, however, that circulatory tests before operation would eliminate the worst cases, which would not be operated upon, and though there is little doubt that operation has benefited a considerable proportion of these patients it is difficult to express the value of surgery accurately by figures Over 80 per cent of those operated on by Adson were able to return to work, with cessation of the disease process in the less affected extremity

Chronic Arthritis—Sympathectomy for chronic arthritis is limited to the treatment of patients whose extremities show cold and clammy skin, with atrophy and contracture of the muscles In such individuals improvement follows the increase in the peripheral circulation produced by warmth, and the value of the operation would seem to lie in its producing prolonged vasodilatation instead of the transient change which accompanies treatment by heat The senile form of osteoarthritis affecting one large joint, and associated with gross bony changes, is unsuitable for sympathectomy, but the operation is indicated in the polyarticular rheumatoid

variety, especially when the joints involved are those of the hands or feet, and the wrists or ankles

What usually happens is that while the patient is in bed after the operation there is a remarkable improvement, with immediate and almost complete relief of pain Then during the convalescent period there is often a relapse, which may be discouraging unless it is realized that with a continuation of physiotherapy, exercises and massage a gradual improvement extending over many weeks or months is to be expected Here, again, the selection of suitable cases is greatly assisted by testing the effects of heating the body, or of spinal anæsthesia, *those showing the greatest improvement in the* peripheral circulation being those most likely to derive benefit from the operation

It must not be imagined that the more proximal joints of the limbs cannot be improved, for we have observed a most gratifying result in chronic arthritis of the shoulder-joint *in a woman aged fifty-seven years For eight months there* had been gradually increasing pain and stiffness in the right shoulder and wrist following a period when the arm had been immobilized for the treatment of an injury to the hand When she came to us there was painful limitation of movement in all the joints of the right upper limb, with muscular wasting, but no nerve lesion She was unable to write or to work, and the most serious complaint was the pain in the right shoulder Immediately after right cervicothoracic ganglionectomy the warm right arm felt more comfortable, and three months later she was able to do her usual housework, movements of the shoulder-joint were full and painless and she was able to write There has been no recurrence of the trouble, and she remains well three years after the operation

Poliomyelitis—Apart from the loss of power in the voluntary muscles and the deformities resulting therefrom, the treatment of which lies in the domain of orthopædics, two other conditions frequently observed among the after-

effects of acute anterior poliomyelitis have been treated with success by sympathectomy—namely, the impairment of the circulation and the shortening of the paralyzed limb The affected extremity is always colder and bluer than its healthy fellow, but not infrequently complications, such as chilblains, sores or even deep ulcers, appear in the cold weather and necessitate treatment in bed for weeks or months

The cause of this circulatory failure is obscure There is no evidence that the disease involves the grey matter of the lateral horns which supply the preganglionic fibres of the sympathetic outflow, and even if it were diseased this would presumably lead to abolition of the vasoconstrictor function of the sympathetic neurons, and the limb would not be cold There is nothing to favour the suggestion that vasodilator fibres are affected either directly by the disease, or as the result of some reflex interference, and the most likely explanation seems to be that the peripheral circulation is poor because the inactive muscles fail to produce the metabolites which are essential for the mechanism controlling the normal circulation Sympathetic ganglionectomy may be of value, not because the operation abolishes a vicious over-action of the sympathetic, but because paralyzing the vasoconstrictor nerves is one means of producing vasodilatation If in time the paralysis of the vessel walls thus induced passes off and there is a recovery of vascular tone, the beneficial effect of the operation will be diminished or lost

Here again it is important to carry out the observations of skin temperature of the affected extremity when the body is warmed or a spinal anæsthetic is administered, in order to determine the cases which are suitable for operation

Ogilvie,[27] in a comprehensive review of the present position of sympathectomy in the treatment of poliomyelitis, publishes four of his own cases, in all of which improvement occurred immediately after the operation One of these patients had a recurrence of ulceration in the winter

following the operation, and it may be that her vessels, in the course of paralysis lasting forty years, had suffered some organic obliterative change, but such relapses have been recorded by other observers, and in younger patients the relapse must be due to recovery of vascular tone

When the lower extremity is involved, the operation to be performed is the lumbar ganglionectomy described for the treatment of Raynaud's disease, but as only one leg may be involved, it is often an advantage not to open the peritoneal cavity, but to perform the operation by the lumbar approach

In addition to the poor circulation, the shortening of the affected limb may be improved by sympathectomy There is a certain discrepancy between the results of animal experiment and of operations upon patients, whether suffering from poliomyelitis or not Bisgard,[28] experimenting on young kid goats, showed that bone growth was unaffected by sympathectomy, and this finding conforms with Cannon's observations on infant rats and kittens after hemisympathectomy

Harris,[29] however, has observed lengthening of a limb deprived of its sympathetic supply when this operation has been carried out for poliomyelitis Also after left lumbar ganglionectomy for megacolon, when there had been no preoperative abnormality of the limbs, he noted that the left leg subsequently grew more rapidly than its fellow Ogilvie and others have also observed this gain in length of the affected limb in poliomyelitis, and the important thing is that if some length is once gained it cannot be lost again, even though the vascular benefit may not be permanent

Scleroderma —The term scleroderma includes at least three different sub-groups of the disease, only one of which is likely to derive any appreciable benefit from sympathectomy

True scleroderma may be diffuse, affecting the skin of the whole body more or less uniformly, or it may be circumscribed, when rounded or oval patches of indurated skin occur on the chest or limbs without any obvious cause for

the distribution of the lesions The stiffening of the skin usually comes on insidiously and without any associated local vasomotor phenomena, and these forms of true scleroderma are so unlikely to be improved by sympathectomy that the operation does not seem to be justifiable

There is a third group, however, in which vasomotor phenomena of the "Raynaud" type occur in the skin of the exposed parts of the body, the skin so affected subsequently losing its soft texture and its elasticity and acquiring the characteristic appearances of scleroderma The peculiar distribution suggests that exposure to cold produces the vasomotor changes which lead to the hardening of the skin

In such cases the usual tests should be carried out to determine the degree of spasmodic as opposed to organic occlusion of the vessels, and should the tests show a satisfactory rise in the temperature of the skin of the affected part with sympathetic inhibition or paralysis, then sympathectomy may be carried out with a reasonable hope of success The stretched appearance and puckering of the skin which characterize the disease are lost after the operation, and in many cases the natural smoothness and softness return, and, instead of being white, the skin recovers its normal pinkish hue If, however, the skin temperature tests are unsatisfactory, it means that organic vascular disease has become superimposed upon spasm, and improvement after sympathectomy cannot be anticipated

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CHAPTER III

SYMPATHECTOMY FOR DISORDERS OF THE VISCERAL MOTOR MECHANISM

1 **Alimentary Canal**—The modern conception of the control of intestinal movement may be said to date from the work of Bayliss and Starling on peristalsis, published in 1899, when they showed that peristalsis is a co-ordinated reflex in which a wave of contraction, preceded by a wave of relaxation, passes along a hollow viscus The stimuli which give rise to normal peristalsis are largely mechanical and chemical from the food being conveyed along the intestine, and it is believed that the reflex path lies in Auerbach's and Meissner's plexuses, the anatomical connections of which have recently been studied in great detail by Catherine Hill[1] Nerve fibres which are believed to be afferent, conveying impulses arising from stimulation by the food, pass from the intestinal villi into the plexus in the muscle layers, and extrinsic fibres from the vagus and sacral autonomics (parasympathetic nerves), and from the sympathetic, also terminate in this intermuscular plexus

It is known from physiological experiment that stimulation of the parasympathetic nerves increases the tone of the intestine and renders its movements more active, whereas stimulation of the sympathetic diminishes tone and arrests peristaltic movement But it has also been shown that peristalsis can go on after all the extrinsic nerves of the intestine have been severed, and according to Gunn it is possible for intestinal muscle to contract rhythmically even after its intrinsic plexuses have been stripped off

It has long been thought by clinicians that, although

animal experiments might tend to show that the gut may be capable of acting satisfactorily when deprived of its nerve supply, in man the control of intestinal movement through the extrinsic nerves is a more important factor, not only in certain reactions which take place in normal individuals, but also in the phenomena of disease Surgical experience gives support to this view, and the success of surgical operations on the extrinsic nerves suggests that these are more important than physiologists have made them out to be The truth probably lies somewhere between the two extremes, and it may well be that intestinal movements will take place even if the extrinsic nerves have been severed, but the function of these nerves is to regulate intestinal movement by acting upon the intrinsic plexuses It may be mentioned here that the plural is used deliberately, for although Bayliss and Starling believed Auerbach's plexus to be the only structure controlling the myenteric reflex, evidence has since been brought forward to show that Meissner's plexus is also of importance in this respect

The conception of a co-ordinated reflex underlying peristalsis must be extended to include the activity of the sphincters, the true significance of which was pointed out by Keith in 1903 Since that date much experimental and clinical work has been devoted to the study of the sphincters of the alimentary canal, more especially by Elliott and by Hurst in this country Keith's view is that in the situations where sphincters are recognized, and particularly at the cardiac orifice of the stomach, the pylorus, the terminal ileum and the descending colon, there are aggregations of what he has called "node tissue," similar to that of the auriculo-ventricular bundle in the heart He has described this as tissue in which the cells of the nerve fibres become continuous with muscle fibres, so that it is hard to say where nerve cells cease and simple muscle cells begin It is thus intermediate between non-striped muscle and sympathetic nerve tissue, and is endowed with automatic power

of originating contractile impulses and muscular movements

In 1895 Langley and Anderson demonstrated that stimulation of the lumbar sympathetic ganglia caused inhibition of peristalsis, with dilatation of the colon and contraction of the internal rectal sphincter, and in 1904 Elliott showed that the tone of the ileo-cæcal sphincter depends upon its sympathetic nerve supply, for section of the splanchnic nerves was followed by permanent relaxation of the sphincter, so that the contents of the small and large intestines intermingled If this be true for one of these sphincters it is likely to be true for the others, and this assumption has been justified by the results of the operations to be described later

Twenty years ago intestinal stasis was explained by the leaders of surgical opinion on mechanical grounds The intestine was regarded as a tube subject to obstruction by kinking, which caused subsequent atony of the portion proximal to the kink Discussing this subject in a paper published in 1915, Keith[2] wrote "I am convinced that in the great majority of cases which are classified under the somewhat elastic term of 'intestinal stasis' the symptoms do not result from an atony of the musculature of the bowel, but from a hypertonicity of those parts which are normally in a state of tonic contraction, such tracts as the terminal part of the ileum, and all that part of the colon which lies between the mid-point of the transverse colon and the junction of the iliac with the pelvic colon" He suggested that the node tissue might be normal in itself, but over-dosed with adrenalin, or subject to some other over-stimulation

In spite of Keith's plea to regard the colon as a neuromuscular organ rather than as a sewage pipe, nearly fifteen years had to elapse before surgeons thought of applying his ideas to practice Even then the notion of operating upon the sympathetic system to influence bowel movement seems to have originated in an accidental, or at least incidental, observation by Royle, who noted that when he had operated

upon the lumbar sympathetic trunks for the treatment of spastic conditions of the legs, certain of his patients who had previously suffered from chronic constipation were relieved of this condition

The case for the neurogenic origin of megacolon has been well argued by Adamson and Aird,[3] who dismiss the mechanical theory because of the not infrequent occurrence of an associated dilatation of the bladder, which in their view can be accounted for only by some abnormality in their common nerve supply They also describe experiments in which megacolon was produced by cutting the nervi erigentes, thus upsetting the normal balance between sympathetic and parasympathetic functions, and creating a relative excess of the sympathetic activity

Assuming, then, that over-action of the sympathetic supply to a portion of the alimentary canal could lead to inhibition of the viscus and contraction of its sphincter, with consequent stasis of its content, two problems still remain for solution before surgical treatment can be decided upon The first problem is the clinical recognition of the conditions which are undoubtedly due to sympathetic over-action, and the second is the determination of the nerves which have to be divided The success which attends sympathectomy in a properly selected case of constipation is to be regarded prophetically as a menace to the future of the surgery of the sympathetic system, for the risk of indiscriminate use, which is, in fact, the abuse of the best operations in surgery, is well known

Selection of cases suitable for sympathectomy will involve first of all the exclusion of all those cases of constipation which fall into the already well-recognized groups, and which yield to appropriate medical treatment

To this "negative" evidence may be added circumstantial evidence if manifestations of sympathetic over-activity occur in other parts of the body It may be that as our surgical observations accumulate we may be able to

amplify and rectify the conception of sympatheticotonia put forward by Eppinger and Hess in 1909 Further reference to this subject will be made in the detailed description of some of our own cases, but by way of illustration it may be mentioned that it is not uncommon to find that in addition to severe constipation, a patient may be suffering from inhibition of bladder activity, tachycardia, and a tendency to peripheral vasomotor instability It may be recalled that in Penfield's case of diencephalic epilepsy constipation was a prominent feature

Positive evidence of sympathetic over-action in any segment of the intestine may be difficult to establish, and even the condition commonly referred to as achalasia, which appears at first sight to be a clear instance of such over-action, becomes on closer investigation a matter of real difficulty The term achalasia is applied to cardiospasm and to congenital hypertrophic stenosis of the pylorus, yet in one there is no hypertrophy of the muscle of the sphincter, whereas in the other it is the outstanding feature Achalasia is used to describe the state of the pelvi-rectal sphincter in Hirschsprung's disease, when there appears to be evidence of over-activity of the sympathetic, yet in cardiospasm it is thought that the sphincter remains closed owing to inefficient inhibition by the vagus, and it is doubtful whether the sympathetic is involved Till such ambiguities are removed and our knowledge of sphincteric control in general and of the nerve supply of every sphincter individually is considerably augmented, it will be difficult to decide for certain beforehand whether sympathectomy is indicated or not Herein lies a fruitful field for surgical research At present the most we can attempt is to determine, in any portion of the gut having a dual supply from the antagonistic parasympathetic and sympathetic systems, whether there is evidence of a disturbance of the physiological equilibrium between the two systems, with a preponderance of the sympathetic element

When such a preponderance exists the experiment of sympathectomy is justifiable, but the success of the experiment as a therapeutic measure is not assured, since other factors, such as the contractile power of the intestinal muscle and the functional capacity of the parasympathetic supply, have to be taken into consideration The sympathetic is sometimes referred to as a brake mechanism in the intestinal and urinary tracts, but it is clear that mere removal of the brake will not produce movement unless the motor mechanism is capable of function In the intestine this motor mechanism can be damaged by interference with the nutrition of the musculature, or by lesions of the myenteric plexuses or of the parasympathetic nerves

The most accurate information we are able to obtain at present with regard to the part played by the sympathetic in the production of intestinal stasis in any given case comes from observation, under the X-ray screen, of the effect of spinal anæsthesia upon the movements of the bowel filled with barium This method of studying the effect of paralyzing the sympathetic supply to the bowel was introduced by Scott and Morton[4] in order to forecast the result of the operation of sympathectomy The spinal anæsthetic might be expected to paralyze all the nerves passing to the bowel, motor as well as inhibitory, but the increase in peristaltic activity which is so frequently observed must be taken to show either that the drug has a predominant effect on the finely medullated sympathetic fibres, or else that the intrinsic motor mechanism of the bowel is capable of carrying on intestinal movement provided it is not impeded by the sympathetic The relaxation of the sphincters which results from sympathetic paralysis also helps to explain the rapid passage of bowel content after the administration of a spinal anæsthetic This increased activity of the colon under spinal anæsthesia casts some doubt upon the importance of the parasympathetic supply to the greater part of the large intestine, and as regards megacolon it seems to give

support to the view that this condition is due to a true excess of sympathetic activity

The second problem which has to be faced in planning surgical treatment is the determination of the particular nerves which must be divided in order to denervate the viscus in question without impairing the function of any others It is remarkable how seldom any serious disability results from the removal of considerable portions of the sympathetic system, even portions which we have believed to be of the greatest importance in the bodily economy, and at times one is tempted to wonder whether there can be such a thing as sympathetic insufficiency It may be that peripheral mechanisms capable of automatic action remain to keep up the function of apparently denervated organs, but in spite of such arguments to the contrary it is wise to attempt to preserve intact as much of the sympathetic system as possible

Information about the anatomical distribution of the sympathetic nerves to the viscera is gradually accumulating as the result of painstaking dissection, and from the careful scrutiny of surgical material Since the nerve supply to the large intestine and to the pelvic organs is perhaps better known than that to the upper portions of the alimentary canal, denervation of the colon will be discussed first, and later a brief reference will be made to the operations which have been performed on the nerves supplying the stomach

(1) **Colon**—The most important sphincter in the colon is at the pelvi-rectal flexure In 1833 James O'Beirne drew attention to the function of this flexure, pointing out that under normal conditions the fæces are held up in the pelvic colon and do not pass beyond the pelvi-rectal junction till immediately before defæcation Symington cut sections through the frozen body and was thus able to show a thickening of the circular muscle fibres at this point, and Hurst, as a result of his observations with the sigmoidoscope and the opaque meal, has recorded his belief in the existence of a true sphincter here, of which the action is assisted by the

acute angle formed between the dependent and mobile pelvic colon and the fixed rectum W J Mayo has added further evidence in support of the presence and activity of this sphincter by pointing out that in the last two inches of the pelvic colon the mucous membrane, instead of forming the usual circular folds around the lumen of the bowel, lies in longitudinal folds as though it had been puckered by a constricting force

In the normal individual after a meal, usually after the same meal every day, as a result of the gastrocolic reflex, a wave of peristalsis travels along the colon, the obstruction at the pelvi-rectal flexure is overcome, presumably as a result of relaxation of the sphincter, and the pelvic colon empties itself into the rectum The sudden stretching of the rectal musculature gives rise to the call to defæcation (Hurst)

Achalasia of this sphincter appears clinically either as a severe form in children, which was described in 1886 by Hirschsprung of Copenhagen, or as a milder degree of the same condition of megacolon which is not detected in early years and is compatible with a surprisingly good state of general health Both in children and in adults the disorder is associated with enlargement and hypertrophy of the colon, especially of the pelvic portion, and it is when hypertrophy is sufficient to overcome the action of the unrelaxed sphincter that symptoms may be masked In some cases there may be also achalasia of the internal sphincter of the rectum, this portion of the bowel then participating in the dilatation

Apart from the cases which appear in infancy and childhood, a second group may be recognized, occurring in females much more commonly than in males, being characterized by increasing constipation, and very frequently accompanied by a well-marked defect in micturition Menstrual irregularities are not uncommon in such patients, and the uterus is often of the infantile type The constipation increases to such an extent that the patient's whole life becomes devoted to the requirements of the bowel, until finally

there is little time and less inclination for any other interests Only by copious enemata can any action be obtained, and if nothing is done to assist the bowel it may fail to act for over a week

It is sometimes stated that the condition may arise as a result of an operation upon the uterus, and the suspicion that certain nerves have been interfered with at the operation may be aroused It is more likely that the uterine condition is an associated phenomenon for which an ill-advised but anatomically harmless operation has been undertaken while the bowel condition has gradually been assuming the dominant rôle In one of our patients constipation was alleged to have appeared six months after hysterectomy for menorrhagia But she had been in hospital on several occasions during the seven years prior to the hysterectomy, and the records made during these previous admissions prove that a severe degree of constipation was present at least for the whole of that period

Clinical Features of Megacolon and Intestinal Stasis— The clinical picture of megacolon as it appears in infancy and childhood needs no elaboration, for the severe constipation and abdominal distension cannot be confused with any other disease A barium enema will show the amount of bowel involved

When it occurs in adult life there may or may not be any considerable degree of dilatation of the gut There is reason to suppose that some of the cases may be a mild form of the congenital defect, mild enough, in fact, to have escaped recognition in childhood All the adult cases are included, however, under the heading "intestinal stasis," and they will probably have to remain so grouped till the features distinguishing the true Hirschsprung type from the adult cases of ntestinal stasis can be more accurately determined

The feature which is invariably present is constipation, which becomes progressively worse over a period of months, or more commonly years, being unrelieved by aperients or

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purgatives The only method of stimulating the muscle of the colon to contract with power sufficient to overcome the uninhibited sphincter is the administration of enemata Flatulent distension is a common symptom, and on examination the abdomen is seen to be distended, the distension being due partly to fæcal accumulation, but largely to gas This gives rise to constant discomfort, but when the bowel has not acted for several days there may be severe pain and vomiting, and the picture becomes one of acute intestinal obstruction

If a barium meal be given and followed through into the large intestine, considerable delay in the onward passage of the barium will be observed, and finally the meal becomes held up, usually in the transverse or descending colon It may remain in this position in spite of large doses of purgatives, and repeated lavage may be required to clear the barium out of the bowel Distension will not be observed in all cases, and when it is present it may be taken to indicate a late stage of the disease accompanied by vascular engorgement and resultant failure in the process of absorption of gas from the intestinal lumen Thus the inability to demonstrate distension of the colon by means of a barium meal does not invalidate the diagnosis

A barium enema will run into the bowel without apparent obstruction, and it commonly shows a greater amount of dilatation of the colon than is apparent with a barium meal But the most significant feature is the absence of the normal sensation in the bowel during the enema examination, for pint after pint of barium emulsion can be administered without any complaint of a feeling of fulness or distension Seven pints were run into the bowel before the X-ray picture shown in Fig 34 was taken, yet the patient, who was only fourteen years of age, suffered no discomfort

The crucial test of inducing splanchnic paralysis by means of spinal anæsthesia is then carried out The colon having been filled with barium emulsion, the patient is turned over



FIG 34—MEGACOLON BARIUM ENEMA (SEVEN PINTS) GIVEN WITHOUT DISCOMFORT

Note the flaccid smooth walled descending colon showing no sign of peristalsis

To face Fig 35 between pages ... and ...



FIG 35 —MEGACOLON PICTURE TAKEN A FEW MINUTES AFTER FIG 34 A SPINAL ANESTHETIC HAVING BEEN ADMINISTERED IN THE INTERVAL

A peristaltic wave passing down the descending colon has reached the sigmoid colon Barium was being expelled from the rectum Note especially narrowing of the descending colon, and the deep indentations of the colon and rectum produced by peristalsis

on the left side and a spinal anæsthetic is injected in a dose sufficient to produce analgesia as high as the umbilicus If, as a result of this procedure, the previously inert bowel contracts, then the operation of sympathectomy should be proceeded with

The patient whose skiagram is reproduced in Fig 34 was given such a spinal anæsthetic, and within a short space of time she complained of a colicky pain, a wave of peristalsis was seen to pass along the colon, and a large quantity of the barium emulsion was expelled from the rectum Fig 35 gives a poor impression of the increase in the activity of the colon, for a cinematographic record would be required to do it justice, but the peristaltic wave has passed down the descending colon and can be seen in the upper part of the sigmoid colon

Anatomical Considerations —When the decision to deprive the colon of its sympathetic nerve supply has been made, the next step is to determine which nerves must be divided in order to achieve this object The portion of the colon involved is that nourished by the inferior mesenteric artery This vessel is surrounded by a plexus of sympathetic fibres arising partly from the aortic plexus, but largely from the lumbar trunks by way of the lumbar splanchnic nerves The inconstancy in the arrangement of the lumbar ganglia has been referred to in an earlier section, but as a rule there are two large branches from each trunk, the lumbar splanchnic nerves, issuing from the second and third ganglia, and passing medially and downwards to form the lateral roots of the presacral (hypogastric) nerve, through which the rectum, bladder and other pelvic viscera receive their sympathetic supply Each lateral root of the presacral nerve gives branches to the inferior mesenteric ganglion and the plexus which surrounds the inferior mesenteric artery, and the sympathetic fibres contained in this plexus accompany the branches of the artery to the bowel (Fig 36)

Learmonth, experimenting on dogs, has been able to show

that section of these sympathetic nerves accompanying the inferior mesenteric artery leads to immediate increase of intracolonic pressure, and may lead to increased amplitude of contractions in the colon

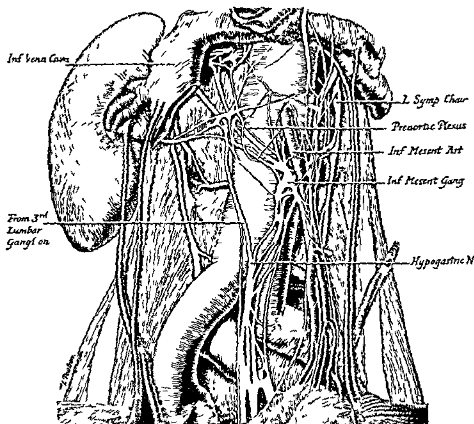


FIG 36—A DISSECTION OF THE PREAORTIC PLEXUS, AND OF THE SPLANCHNIC BRANCHES OF THE LUMBAR GANGLIONATED TRUNKS WHICH PASS MEDIALLY TOWARDS THE FRONT OF THE AORTA TO FORM THE INFERIOR MESENTERIC PLEXUS AND GANGLION, AND THE HYPOGASTRIC (PRESACRAL) NERVE

Note the numerous bundles passing downwards and medially to converge below the origin of the inferior mesenteric artery, and also how sympathetic fibres ensheathe the artery and are distributed along its branches

For many years it has been accepted that the left side of the colon receives its motor supply from the sacral autonomics (S 2, 3 and 4), but, *until the publication of* Stopford's *recent* work on this subject, nothing was known about the path

these nerves follow to reach the colon Stopford has been able to show by dissection that the sacral fibres travel in the nervi erigentes (pelvic nerves), through the pelvic plexuses and up the presacral nerve as far as the origin of the inferior mesenteric artery, where they curve downwards again at an acute angle to join the plexus which surrounds the inferior mesenteric artery Sympathetic and parasympathetic nerves to the left side of the colon thus meet at the origin of the inferior mesenteric artery, the former coming from above and the latter from below, both running the last part of their course in company with the artery and its branches The anatomical path of these ascending sacral fibres may be traced in Fig 36

Technique and Results of Sympathectomy—The first sympathectomy operations for megacolon were those of Wade and Royle,[5] who carried out an extensive ramisection of the left lumbar gangliοnated trunk, finally dividing the trunk below the fourth lumbar ganglion This operation, slightly modified in that ganglionectomy replaced ramisection, was practised by Judd and Adson,[6] Robertson,[7] and Bagot Oldham[8] with remarkable success, for improvement both in bowel movement and in X-ray appearances occurred in the greater proportion of the reported cases, although only the left lumbar trunk was operated upon These surgeons and others have carried out bilateral lumbar ganglionectomy with good results, but the published reports give little indication that the removal of the right trunk contributed any appreciable benefit, though on anatomical grounds the bilateral operation must be considered the more rational procedure

The results of these operations may be summarized by saying that some improvement in the action of the bowels occurred in all the cases, and a certain number continued to have regular actions without aperients for periods up to two years after the operation Sufficient time has not yet elapsed for the late results to be known Wade has expressed

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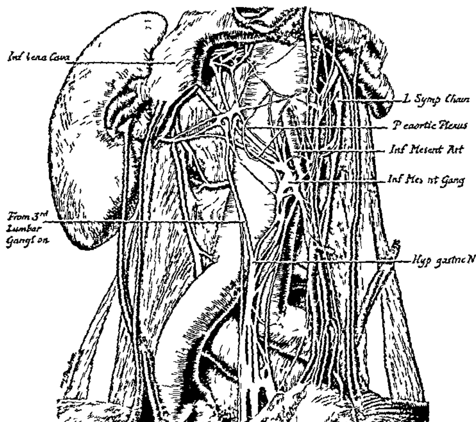


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the opinion that the cases may be divided into two groups, one in which the colon shows gross dilatation, hypertrophy and visible peristalsis, and in which the operation gives excellent results, and the other in which hypertrophy of the gut is not a marked feature and in which only moderate improvement is to be expected

It happens not infrequently that, though the bowel acts daily during the postoperative period in hospital, constipation reappears after the patient returns home This has been noted so often when the final result has been satisfactory that the occurrence of such a relapse should be taken to indicate the necessity for more careful attention to the patient's exercise, habits, and diet, and perhaps for the administration of mild laxatives, for by such simple measures regular bowel function may be established After all, it must be remembered that normal individuals need to take reasonable care to ensure regularity in the action of the bowels, and nobody would wish to claim for sympathectomy supernatural powers which could transform the bowel of megacolon into a perfect machine which, unlike the "normal" colon, could be relied upon to function smoothly for ever without any care or attention

An attempt should be made to assess the physiological effect of the operation by repeating the preoperative X-ray investigations without, of course, the administration of a spinal anæsthetic The usual finding is that the colon is still dilated, though less so than before operation, that its contour shows more numerous and deeper haustrations, and that the barium meal passes more rapidly along the bowel, the time taken for the meal to reach a given point approximating to the normal

Many who have devoted special attention to the problems of megacolon believe excision of the second, third and fourth lumbar ganglia to be the best method of treatment, but others follow Rankin and Learmonth[9] in carrying out what is, in their opinion, a more radical sympathectomy

This entails division of the presacral nerve over the sacral promontory, and the stripping of its middle and lateral roots off the left common iliac vein and the bifurcation and anterior aspect of the aorta as high as the origin of the inferior mesenteric artery. The sympathetic fibres, converging upon the origin of this vessel from above and from the sides, are all divided, and finally the proximal inch of the artery is completely bared, so that all the sympathetic nerves running with it to the bowel are interrupted (Fig 37). It has been mentioned above that sacral autonomic fibres are also severed in this operation, and until we have more direct evidence regarding their importance it is difficult to say whether it is right to sacrifice these fibres to make certain of cutting all the sympathetic supply.

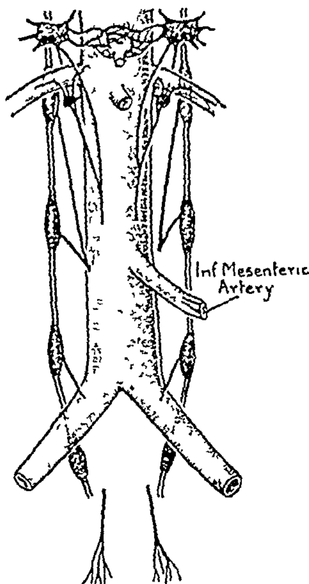


FIG 37.—DIAGRAM TO INDICATE THE PORTIONS OF THE PREAORTIC PLEXUS, INFERIOR MESENTERIC PLEXUS AND PRESACRAL NERVE REMOVED IN THE OPERATION OF RANKIN AND LEARMONTH

(Compare Fig 4, p 9)

In order to achieve complete sympathectomy without damaging the parasympathetic supply, it might be preferable to excise the second, third and fourth lumbar ganglia, or

the opinion that the cases may be divided into two groups, one in which the colon shows gross dilatation, hypertrophy and visible peristalsis, and in which the operation gives excellent results, and the other in which hypertrophy of the gut is not a marked feature and in which only moderate improvement is to be expected

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the distension was confined to the colon, mostly in its distal portion

Operation was performed on May 30, 1930, and consisted of bilateral lumbar ganglionectomy and stripping the first inch of the inferior mesenteric artery From the day of operation she began to pass her water at regular and more frequent intervals, and after she was allowed up her bowels acted twice daily without aperients Eighteen months later her general health had improved greatly, she was less indolent, and the abdomen showed no distension The bowels continued to act regularly with an *occasional aperient* Barium meal and enema examinations at this date showed that the colon was less distensible and more active than it had been before operation

The second case of congenital megacolon was that of a child fourteen years of age who sometimes went for six weeks without an action of the bowels and had frequent bouts of vomiting Skiagrams of the barium enema examination are reproduced in Figs 34 and 35 (p 117) She presented the typical picture of Hirschsprung's disease, and was treated by excision of the inferior mesenteric plexus and presacral nerve in November, 1932 The immediate result was diminution in the abdominal distension and a regular daily action of the bowel with liquid paraffin A report in July, 1933, states that as a rule "she manages without medicine, and if her bowels miss one day she is given a pill, which puts her right"

Our patients with intestinal stasis were women, aged thirty-eight and thirty-four, who both complained of long-standing and steadily increasing difficulty with the bowels, accompanied by frequent attacks of abdominal pain, lassitude, and inability to work on account of this condition Both patients had infrequent micturition owing to loss of the normal sensation of fulness as urine accumulated in the bladder, and both suffered from irregular menstruation Barium meal examinations showed great delay in the onward

to divide their splanchnic branches on both sides, and to excise the preaortic plexus for an inch above the inferior mesenteric artery, leaving the presacral nerve undisturbed This is practically the technique advocated by Trumble,[10] the only difference being that he is content to divide the lumbar splanchnic nerves just proximal to the inferior mesenteric ganglion, since he believes that the preaortic plexus takes no part in the sympathetic supply to the colon He quotes his experience of four cases of intestinal stasis and one case of megacolon in support of his argument, and to show that good results are obtainable by this operation

The literature contains a rapidly increasing number of references to cases of megacolon treated by one of these forms of sympathectomy, but, though most of the early results are encouraging, sufficient time has not yet elapsed to enable us to assess the permanent value of these operations

Rankin and Learmonth[11] have published their results in a series of eight cases of megacolon In three cases lumbar ganglionectomy was performed with good results, and in five their own operation of resection of the presacral nerve with the inferior mesenteric plexus gave good results in three cases and great improvement in the remaining two

Barrington Ward[12] has described three children with Hirschsprung's disease from whom he removed the inferior mesenteric plexus and presacral nerve with very gratifying immediate results

We have operated upon two patients with congenital megacolon, and two adults suffering from intestinal stasis with a moderate amount of dilatation of the colon Our first patient was nineteen years of age and could never remember her bowel acting without medicine She was emotional, and below the average in intelligence Purgatives being of no avail, regular enemata became necessary Micturition had always been infrequent, and it was retention of urine which finally brought her under our care Her abdomen was greatly distended, and X-ray examination showed that

and many suggestions have been thrown out about the possible relationship between ulcer of the stomach and duodenum and the sympathetic innervation of these organs So far, however, these have been almost entirely conjectural, and the most illuminating contribution to the subject of the nervous element in the production of peptic ulcer is Cushing's[13] evidence indicating the importance of the parasympathetic system in this respect On theoretical grounds one would expect the parasympathetic to be the dominant factor, since the vagus is the secretory nerve to the stomach, and the only way in which over-activity of the sympathetic might predispose to ulcer formation would be by inducing pyloric spasm

Hahn has reported two cases of atony and ptosis of the stomach associated with pyloric spasm in which Bircher divided the splanchnic nerves X-ray examination after operation showed that the stomach had returned to normal size and that the pylorus had relaxed

When the opportunity occurs, a great deal of information is likely to be obtained from the analysis of the gastric juice before and after division of the sympathetic and vagal supply to the stomach in man In regard to peptic ulceration, the influence of these nerves upon gastric secretion may prove to be of even greater importance than their control of the gastric musculature

2 **Urinary Tract—(1) Bladder**—It has been mentioned above that many of the patients upon whom sympathectomy has been performed for megacolon or intestinal stasis also showed evidence of a defect in the motor mechanism of the bladder, which was very greatly improved or even abolished as a result of the operation The intimate anatomical relationship of the origin of the sympathetic nerves supplying the bladder and the lower bowel goes far to explain the fact that both systems share in the benefit obtained from sympathectomy, but in order to understand the nervous mechanisms involved, reference must be made to the investigations of

passage of barium in spite of the administration of purgatives, and the colon could be distended with large quantities of barium emulsion without causing discomfort The first also complained of cold, clammy hands and feet

They were both operated upon by excision of the inferior mesenteric plexus and presacral nerve, the first in November, 1931, and the second in October, 1932 The result in the first case was a most dramatic improvement, which, apart from an occasional brief set-back, has been maintained for two years In the second case, stripping the inferior mesenteric artery presented considerable difficulty, and, perhaps because the operation may have been incomplete, although abdominal distension disappeared, the bowel still requires the judicious use of aperients, which, though formerly ineffective, now induce adequate movements of the bowel In both cases the sensation of fulness of the bladder was recovered, and frequency of micturition, therefore, became normal

(ii) **Œsophagus**—It has been suggested that the condition commonly referred to as "cardiospasm," or "achalasia of the cardia," might be amenable to treatment by sympathectomy Before such treatment can be placed on a rational basis more information is required with regard to the anatomy of the sympathetic supply to the œsophagus, and the rôle which the sympathetic plays in deglutition

It will also be necessary to define more clearly the site and the nature of the pathological process in cardiospasm, and should it be established, as it is commonly supposed, that an inflammatory or degenerative lesion of Auerbach's plexus is invariably present, division of the sympathetic supply proximal to Auerbach's plexus would not be expected to be beneficial These problems involved in the proposal to treat cardiospasm by sympathectomy are in urgent need of solution

(iii) **Stomach**—The splanchnic nerves have been divided occasionally in the hope of benefiting disease of the stomach,

mesenteric artery It is more likely, however, that all the cells are not massed at this spot in man, but are distributed

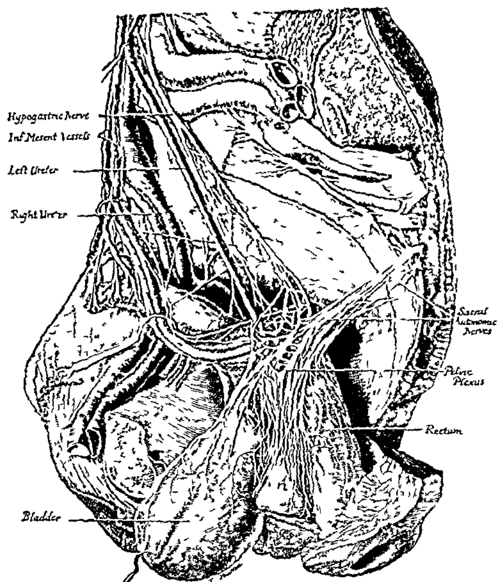


FIG 39 —DISSECTION SHOWING THE DISTRIBUTION OF THE HYPOGASTRIC (PRESACRAL) AND PELVIC NERVES

The sacral autonomic (pelvic) nerves are arising from the sacral spinal roots and have no connection with the lower end of the gangliionated trunk of the sympathetic The portion of the presacral nerve removed at operation is that shown at the top of the dissection, lying upon the bifurcation of the aorta, the left common iliac vein, and the lumbo sacral intervertebral disc The left ureter has been drawn across the front of the presacral nerve in this region

along the course of the presacral nerve as far down as the inferior hypogastric plexus

Elliott and Barrington upon animals, and those of Head and Riddoch, and more recently of Learmonth[14] into the physiology of the urinary bladder in man

It is believed that micturition is controlled by impulses passing along three pathways (Fig 38)

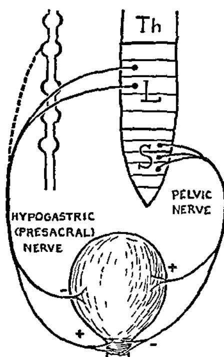


FIG 38—DIAGRAM OF ANTAGONISTIC SYMPATHETIC AND PARASYMPATHETIC NERVE SUPPLY TO BLADDER

Pelvic nerve=sacral autonomic (*a*) in text, presacral nerve= sympathetic (*b*) in text dotted line from ganglionated trunk to presacral nerve indicates possible sympathetic supply through the preaortic plexus and middle root of presacral nerve

(*a*) By the pelvic nerves (sacral autonomic nerves, nervi erigentes), which contain afferent as well as efferent fibres, the efferents being motor to the detrusor muscle and inhibitory to the internal sphincter, this supply being essential for micturition

(*b*) By the presacral (hypogastric) nerves, which also contain afferent and efferent fibres, the efferents being inhibitory to the detrusor muscle and motor to the internal sphincter

(*c*) By the pudic nerves, which contain afferent fibres from as high as the neck of the bladder, and efferent motor fibres to the external sphincter

The presacral nerve descends towards the hollow of the sacrum, and each lateral division ends in the inferior hypogastric or pelvic plexus on the lateral aspect of the rectum, where it is joined by branches of the second and third sacral nerves destined to supply the bladder (Fig 39) It is sometimes stated that the postganglionic fibres for the bladder arise from cells in the inferior mesenteric ganglion, which lies upon the aorta just below the origin of the inferior

so preventing a rise of pressure within the bladder as urine collects in it, then the return of the sensation of fulness after sympathectomy will be readily understood

It must be pointed out here that the feeling of fulness in the bladder which gives rise to the desire to micturate is a sensation quite distinct from the pain of an over-distended bladder, and these two sensations travel centrally by different pathways Head and Riddoch recorded the case of a man with a complete transverse spinal cord lesion at the fourth lumbar segment who felt the pain of his over-distended bladder, and referred it to the suprapubic region along the lowest thoracic and the first lumbar dermatomes The only afferent path for such pain sensation would be along the presacral nerve, and the suggestion that this is, in fact, the path is supported by the experience of Foulds,[15] whose patient suffered from pain of over-distension of the bladder before, but not after, resection of the presacral nerve On the other hand, there is no doubt that the sensation of fulness of the bladder which normally initiates the act of micturition is not diminished by excision of the presacral nerve, and the afferent path for this sensation must therefore lie in the sacral nerves The patient described by Foulds was suffering from a fracture dislocation of the second lumbar vertebra, with a lesion of the third to the fifth sacral segments, and he never experienced the desire to micturate after the occurrence of the accident

Seeing that the act of micturition is under the control of two antagonistic sets of nerve impulses, retention of urine may be produced either by over-action of the sympathetic, or by lesions of the spinal cord or cauda equina causing a defect in the sacral parasympathetic function If the sacral supply be completely destroyed micturition becomes impossible, but a partial lesion may spare a certain proportion of this parasympathetic supply which will be overwhelmed, however, by the activity of the sympathetic nerves arising from the normal lumbar region of the spinal cord Such

Learmonth[14] has had the opportunity of stimulating the presacral nerve in patients under spinal anæsthesia, the bladder being observed through a cystoscope He noted that *stimulation of the presacral nerve caused contraction of the* ureteric orifices, increased tonus of the trigone, contraction of the internal sphincter, and constriction of the vessels of the trigone, the opposite effects being produced by section of the nerve He also brought forward evidence, from observations made upon man, that stimulation of the sympathetic by adrenalin causes a fall in intravesical pressure

We have observed transitory increased frequency of micturition in our own patients after resection of the presacral nerve This may be explained by supposing that the desire to micturate, which is a response to increasing intravesical pressure, can be produced by a smaller volume of urine than was necessary to produce this sensation before sympathetic inhibition of the detrusor was removed

Although the sympathetic fibres reaching the bladder through the presacral nerve are motor to the internal sphincter, even in the female incontinence of urine does not occur after resection of this nerve Since micturition can be carried out naturally after ablation of the presacral nerve, it is clear that only the sacral supply to the bladder is essential for micturition, though the over-action of its sympathetic antagonist may produce symptoms

In the case of our patients who were deemed to be suffering from relative over-action of the sympathetic supply to the colon and bladder, the trouble seemed to be an absence of the normal desire to micturate, and in one of them, who neglected to empty her bladder at regular intervals, attacks of retention of urine After the presacral nerve or, in one instance, the lumbar splanchnic nerves had been cut, the desire to micturate returned, the stimulus being the accumulation of a certain volume of urine in the bladder If it be allowed that the sympathetic can cause inhibition of the detrusor muscle, acting as a "brake" on this muscle and

peritoneum is sutured, and the abdomen is then closed in the usual manner Whether the operation be a therapeutic success or not, it is unattended by any defect in micturition or defæcation, but it is necessary to warn male patients that following the operation, though still potent, they will be sterile

(ii) **Ureter**—Intravenous pyelography is sometimes regarded as an alternative to the method of retrograde pyelography for visualizing the outline of the renal pelvis The real advantage, however, of the intravenous method is that it may be used as an indicator of the functional efficiency of the kidneys, and that it enables us to study the passage of urine along the whole length of the urinary tract under natural conditions It thus brings to light any delay in the outflow from the renal pelvis or ureter, as well as any deformity or dilatation of the urinary passages, and the method has therefore caused renewed interest in the problem of hydro-ureter

When considering the nerve supply of the ureter we must confess, as in the case of the œsophagus, that we are uncertain of the anatomical details, and of the function of such nerves as are known to be present in the wall of the ureter It is assumed that there are sphincters at its upper and lower extremities, and since sympathetic fibres reach the ureter along its bloodvessels it is also assumed that the impulses conveyed by these sympathetic fibres are motor to the sphincters Stimulation of the presacral nerve, which conveys sympathetic fibres to the lower end of the ureter, is known to cause contraction of the ureteric orifices

Cystoscopic observations and observations of the effects of adrenalin in a case of extrophy of the bladder seem to indicate that stimulation of the sympathetic also leads to increased flow of urine from the ureters This would agree with the statement which has been made that the ureter receives only a sympathetic supply, yet on anatomical grounds one would expect the upper end to receive a parasympathetic

partial lesions of the conus medullaris or of the cauda equina are very uncommon, but they have been recorded after myelitis or injury, and it is in the treatment of such lesions that presacral neurectomy is of value, since it tends to restore the equilibrium between the weakened parasympathetic and its sympathetic antagonist The final result of the operation will depend, of course, on the amount of function remaining in the sacral segments

Learmonth[16, 17] has described two examples of this rare form of spinal cord lesion, with an account of the benefit which may be derived from presacral neurectomy in such cases Adson, in a more recent report (1933) of the results of Learmonth's work at the Mayo Clinic, states that six out of eight patients in this group received benefit from the operation Though retention of urine is seldom due to this particular form of disturbance of the normal sympathetic-parasympathetic equilibrium, it is important to recognize its existence, since it is possible by sympathectomy to reduce the amount of residual urine to a negligible quantity

Technique of Presacral Neurectomy —The peritoneal cavity is opened by a left paramedian incision, and with the patient in the Trendelenburg position, the small intestine is packed off so as to expose the bifurcation of the aorta and the promontory of the sacrum The peritoneum overlying the aortic bifurcation is incised vertically as far as the brim of the true pelvis The presacral nerve cannot be identified as individual strands, and it is necessary to remove all the fatty and areolar tissue which contains the nerves *The sheet of tissue to be excised lies between the peritoneum* in front, and the last inch of the aorta, the left common iliac vein and the body of the fifth lumbar vertebra behind, and it extends laterally over the first $1\frac{1}{2}$ inches of the common iliac arteries Great care must be taken not to injure the left common iliac vein The middle sacral artery is unlikely to be damaged unless the excision is carried below the sacral promontory, and this is unnecessary The posterior parietal

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supply from the vagus and the lower end from the sacral autonomics This is clearly a subject calling for more complete investigation

The importance of hydro-ureter lies in its association with hydronephrosis and infection of the urinary tract, and Ellis and Evans[18] have drawn attention to the presence of this condition in a large proportion of cases of renal dwarfism In the absence of any organic obstruction in the ureter, it is natural to postulate some neuromuscular defect to account for the narrowing of the lumen at the lower end of the ureter, and the great dilatation which occurs above this constriction

Ogier Ward[19] has performed presacral neurectomy for hydro-ureter, and we have operated upon one patient with a degree of improvement similar to that recorded by him Our patient was twenty years of age, and had complained of pain in the right loin for six months He was found to have bilateral hydro-ureter, with much greater dilatation on the right side, and he also had a large stone in a diverticulum of the bladder close to the orifice of the right ureter Uroselectan was held up in both ureters for nearly twenty-five minutes before entering the bladder Repetition of the uroselectan studies after presacral sympathectomy and lithotomy showed persistent dilatation of both ureters, but the dye entered the bladder within about ten minutes of its injection Four months after the operation he was free from symptoms

Ogier Ward has examined one of his patients a year after the operation, and the diminution in the calibre of the ureter which was observed shortly after sympathectomy was maintained, though even after this interval the ureter still showed a very considerable degree of dilatation In this respect the result of sympathectomy for hydro-ureter is similar to that for megacolon, for in both cases the function of the viscus is improved but the dilatation persists

which connected it with the second and third sacral ganglia of the lateral sympathetic trunk In 1898 he published his method of cutting these fibres by an approach from the perineum, but as the operation was followed by retention of urine, owing presumably to damage to the sacral autonomic nerves to the bladder, it had to be abandoned The next attempts were made by Latarjet and Rochet, who excised a portion of the hypogastric plexus in relation to the utero-sacral ligaments, but this operation also produced retention of urine Lériche advocated periarterial sympathectomy of the internal iliac arteries, but the operation was difficult to carry out, and, though sometimes brilliantly successful, could not be undertaken in the confident expectation of a satisfactory result

The whole aspect of the subject became completely changed in 1925, when Cotte and Dechaume[1] described their operation of excision of the presacral nerve and its value in gynæcology The technique is that described in Chapter III (p 130), and this procedure has been widely practised for dysmenorrhœa Of the large number of papers on this subject which have appeared during the past few years, one of the most comprehensive is that by Fontaine and Herman,[2] which includes, in addition to their own experience, a vast bibliography In selecting the cases suitable for this operation it is important to exclude all except those in which dysmenorrhœa is of the spasmodic type, and in which the pain occurs only immediately preceding and during menstruation, being so severe that all other forms of treatment are unavailing The operation should never be performed for the congestive type of dysmenorrhœa

Though it is possible that section of efferent uterine fibres in the presacral nerve may be a factor in the success of this treatment for dysmenorrhœa, it is probable that most, if not all, the afferent fibres from the uterus travel in this nerve to the spinal cord In addition, it is fortunate that excision of a portion of the presacral nerve is unaccompanied

CHAPTER IV

SYMPATHECTOMY FOR PAIN

1 **Visceral Pain**—The study of visceral pain is a complex problem which does not lend itself to corroboration by animal experiment, and demands an unusual amount of co-operation between the patient, who may be suffering severely, and the investigator, who may be doubtful about the exact mechanism he is testing, since it is manifestly impossible for him to block one by one the various paths which could be followed by the pain impulses in question It is believed that the nerve supply of the viscera is derived exclusively from the autonomic system, and it is therefore certain that these nerves must contain afferent as well as efferent fibres, but the exact nature of the stimuli required to produce the sensations of visceral pain is largely unknown, though evidence is steadily being collected by painstaking methods of clinical research

Sympathectomy has been employed in the treatment of dysmenorrhœa, in an attempt to relieve certain forms of vesical and renal pain, and both sympathectomy and alcohol injection to block sympathetic nerves have been carried out for the pain of angina pectoris Since the treatment of pelvic pain involves portions of the sympathetic system which were under consideration in the latter part of the previous chapter, dysmenorrhœa and vesical pain will be dealt with first

(1) **Dysmenorrhœa**—Jaboulay seems to have been the first to conceive of the idea of treating uterine pain by sympathectomy, and he planned his operation on the assumption that the afferent path from the uterus lay in the small branches

division of the sympathetic chains at the level of the sacral promontory These procedures act in two ways by interrupting a certain number of afferent pain fibres from the bladder, and by improving the local blood supply Therefore both immediate and late effects of the operation may be expected The immediate effects have been encouraging, the early late effects have also been encouraging"

The good effects may also be due, partly at all events, to cutting efferent fibres in the presacral nerve, and so diminishing spasm of the bladder neck

As regards malignant disease, alleviation of pain is to be anticipated only if the growth is still confined to the bladder wall, and if the pain is produced by some disturbance of the function of the bladder musculature When the growth is spreading widely in the pelvis, cordotomy is the only surgical palliative which is likely to succeed

(iii) **Renal Pain**—Harris and Harris[4] have brought forward evidence, largely based on pyeloscopy and the results of their operations, to show that renal pain for which no well-recognized cause can be found may sometimes be due to the presence of what they term "renal sympathetico-tonus" They believe that the ring muscles which surround the outlets of the minor calyces, major calyces and renal pelvis receive their motor supply from the sympathetic, and that over-activity of the sympathetic can lead to spasm of these ring muscles, with resulting distension of the calyces and renal pelvis

Pyelography in such cases reveals slight clubbing and dilatation of the calyces, and dilatation of the renal pelvis, with delayed emptying Reproduction of the pain as a result of distending the renal pelvis provides proof of its true nature, and an injection of eserin may shorten the emptying time, and may abolish the pain The recurrence of pain after its relief by eserin is an indication for sympathectomy

The operative treatment consists of stripping the renal pedicle bare of all the adventitious tissue containing the

by any disability or defect in the action of the bladder or of the bowel As regards menstruation, a "period" may occur during the few days immediately after the operation, but afterwards the "periods" will occur regularly according to the rhythm which they followed before the operation Presacral neurectomy has no deleterious effect upon parturition

In 1929 Cotte published his results in 200 cases, the majority being cured or very greatly improved In the same year Ferey published 50 cases treated by presacral neurectomy, after the operation 23 patients were well, 23 were greatly improved, and in only 4 was the operation a failure Of Fontaine's 15 cases (1932), 13 remained cured, some for as long as four years after operation, and 2 were unrelieved We have had the opportunity of following up 20 patients operated upon by Dr Malcolm Donaldson at St Bartholomew's Hospital Most of these women had been forced to give up their employment and retire to bed for several days at the time of the menstrual period, but since the operation the majority have been quite free from pain, and even when persistent, the pain has not been severe enough to interfere with their usual activities

(ii) **Vesical Pain**—Sympathectomy has been carried out in the hope of relieving certain painful lesions of the bladder originating from inflammatory and malignant disease The results in malignant disease are disappointing, but the relief afforded in certain of the inflammatory conditions seems to justify the operation

It is supposed that pain referred to the lower urinary tract may be produced by colicky contractions of the lower end of the ureter, or lesions of the vesico-urethral sphincter apparatus leading to spasm at the bladder neck

Learmonth[3] summarizes his experience as follows "In long-standing cases of cystitis in which the pain and increased frequency do not yield to ordinary measures, resection of the presacral nerve offers an additional method of treatment Resection of the presacral nerve may be combined with

from the cardiac plexus to the upper thoracic sympathetic ganglia, but very little is known about these alternative paths The most dramatic demonstration that in some cases, at any rate, the route by the cardiac branches of the inferior and middle cervical ganglia is the only one occurred during an operation which Leriche was performing under local anæsthesia An attack of anginal pain occurred while Lériche had the inferior cervical ganglion exposed, and he was able to abolish the pain by injecting novocaine into the ganglion

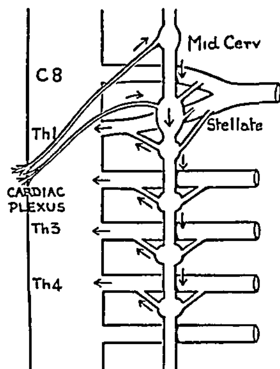


FIG 40—DIAGRAM INDICATING THE PATH OF THE PAIN IMPULSES IN ANGINA

From the cardiac plexus they pass by the sympathetic cardiac nerves to the middle and inferior cervical ganglia and thence down the sympathetic trunk to enter the spinal cord along the white rami communicantes of the upper four or five thoracic nerves

Since all the impulses travelling by this route must pass through the inferior cervical ganglion and the upper end of the thoracic portion of the lateral sympathetic trunk, the simplest and most certain method of blocking their path is to excise the inferior cervical and the first and second thoracic ganglia on the left side, following the technique described for the treatment of Raynaud's disease This was the procedure advocated by Jonnesco in 1916, but it has been criticized by Danielopolu, who considers that the operation carries with it a considerable risk of post-operative pulmonary œdema, or even of sudden cardiac arrest

Danielopolu bases his objections upon certain theoretical

nervous elements, and Harris and Harris recommend that the bloodvessels and the upper end of the ureter be isolated a short distance from the hilum, so that stripping may be carried out towards the kidney

Harris and Harris gave an account of twenty-eight patients and Hess[5] of ten patients so treated, and the results of their operations justify a more extended trial of this method of treating renal pain, which might perhaps be extended to include the early stages of the pelvic type of hydronephrosis, the cause of which is thought to lie in a neuromuscular defect

(iv) **Angina Pectoris** —Anginal pain may be regarded as a danger signal Since in a very large proportion of cases the pain is produced by a definite amount of muscular effort, the amount of exercise undertaken by the patient will be limited to what may be accomplished with comfort, and the strain placed upon the heart will thus be kept within the bounds of safety

If, however, the patient is comparatively young, and if there is not evidence of cardiac embarrassment such as to lead one to anticipate a sudden failure of the heart, it is justifiable to undertake treatment which will relieve the patient's suffering, even though the warning function of the pain be lost thereby

According to Ranson, the afferent path from the heart lies in the vagus and in the sympathetic, the vagal fibres being the afferent path for the cardiac reflexes, and the sympathetic providing the path for pain The sympathetic nerves involved are the middle and inferior cardiac nerves which join the lateral trunks at the middle and inferior cervical ganglia, and afferent impulses travelling along them would pass down the lateral trunk to enter the spinal cord by way of the white rami communicantes of the upper four or five thoracic roots (Fig 40) Though both sides may be involved, the phenomena are usually confined to the left side

It is possible that other routes exist running directly

abolished the pain in about 65 per cent of his cases of angina

As an alternative to ganglionectomy, White[7] has advocated paravertebral alcohol injection, with the object of bathing the upper five thoracic ganglia and rami with 80 per cent alcohol, thus blocking the conductivity of the afferent path close to the spinal cord He has recorded the results of this treatment in 17 cases No serious accidents occurred, but 3 patients developed pleurisy which rapidly cleared up Seven patients were completely relieved, 3 were only slightly improved, and 2 suffered as severely as before Five patients were able to return to work, and it was noticed that though the danger signal of left-sided anginal pain had disappeared, shortness of breath and a peculiar precordial sensation, or even a mild attack of right-sided pain, sufficed to warn the patient that he had reached the limit of safety

We have had the opportunity of treating one patient by White's method He was a railway carriage washer, thirty-eight years of age, who was under the care of Dr Geoffrey Bourne in St Bartholomew's Hospital For four years he had suffered attacks of angina major, which occasionally necessitated rest in bed Shortly before admission to hospital the attacks had gradually become more severe and more frequent, recurring three or four times every day There was no gross arterial degeneration, the electrocardiogram was normal, the Wassermann reaction negative, and the chest radiographically normal

The injection was carried out following White's technique, except that four instead of five ganglia were injected Four fine, long needles were inserted at right angles to the skin surface at points 4 cms from the mid-line, and so as to strike the inferior borders of the first, second, third and fourth ribs on the left side The point of each needle in turn was slipped just below the rib, and the needle was then inclined inwards and slightly downwards at an angle of 45 degrees to the surface and pushed on for about 2 cms till the point

considerations, his main argument being that as the sympathetic is vasodilator and the vagus vasoconstrictor to the coronary vessels, sympathectomy is likely to lead to intense spasm of the coronary vessels and death from heart failure That this is not so in practice has been shown by the results of the large numbers of ganglionectomies which have been performed for angina It has also been shown, both in animals and in man, that after bilateral cervicothoracic sympathectomy acceleration of the heart can still be produced reflexly, and there is no clinical or experimental evidence to show that this operation incapacitates the heart in any way

Many sufferers from angina may be unfit to stand an operation of the magnitude of cervicothoracic ganglionectomy, but the alternative suggested by Danielopolu is a much more extensive, lengthy and difficult procedure He considers it safer to leave the inferior cervical ganglion intact, but he removes the cervical sympathetic trunk above it, and he cuts the rami communicantes connecting the inferior cervical and first thoracic ganglia with the sixth, seventh and eighth cervical and the first thoracic nerves, the vertebral nerve, and the nerves forming the anastomosis between the superior laryngeal nerve and the vagus His low mortality he attributes to the fact that care is taken to avoid injury to the inferior cervical ganglion This complicated operation can be attempted only by those who are as familiar as Danielopolu himself with the anatomy of these innumerable and minute nerves, and even he admits that the result may be unsatisfactory because the operation has been incomplete

Many other operations have been performed with varying degrees of success, though it is hard to explain why some of them have any effect at all In 1923 Coffey and Brown reported five cases of angina pectoris in which removal of the superior cervical ganglion or division of its cardiac branches had sufficed to alleviate the pain, but Cutler[6] has estimated that not more than 45 per cent of such operations give good results, whereas cervicothoracic ganglionectomy

PLATE XII



FIG 41—PHOTOGRAPH OF PATIENT AFTER ALCOHOL INJECTION OF UPPER THORACIC SYMPATHETIC TRUNK ON LEFT SIDE HORNER'S SYNDROME PRESENT ON LEFT SIDE

[To face page 142

was close to or in contact with the vertebral body just anterior to the head of the corresponding rib With the needles in this position 5 c c of 1 per cent novocaine was injected through each needle After waiting ten minutes for anæsthesia to develop, 5 c c of 80 per cent alcohol was injected through each needle in turn

Almost immediately Horner's syndrome of cervical sympathetic palsy appeared on the left side (Fig 41), and as it persisted, it indicated that the injection had been successfully carried out, at all events as far as destruction of the first thoracic white ramus was concerned

After the injection the pain did not recur Two days later he experienced the feeling of faintness which had previously accompanied the anginal attacks, but there was no pain He is known to have been free from pain for some months after the injection, but sufficient time has not yet elapsed to enable us to express an opinion upon the permanence of the cure

2 **Causalgia** —Reference has been made in an earlier section to the beneficial effect of sympathectomy in conditions, such as Raynaud's disease and senile gangrene, associated with impairment of the peripheral circulation, and it was noted that although in some cases the improvement in the blood supply to the periphery following the operation might be considered sufficient to account for the cessation of pain, in others the pain disappeared though no demonstrable improvement in blood supply had occurred Before these clinical anomalies can be explained, much more information than we possess at present must be obtained with regard to pain Whether pain can originate from bloodvessels, as well as from viscera and from the skin, whether such vascular and visceral pain is of a different nature from cutaneous pain, what the adequate stimuli to produce vascular and visceral pain may be, and by what paths the impulses created by these stimuli travel to reach the central nervous system, are some of the problems awaiting solution

The study of causalgia affords a good opportunity for

investigating these problems in so far as the bloodvessels are concerned, for though the trouble originates from injury to a peripheral nerve, its manifestations are a rather bewildering mixture of nervous and vasomotor phenomena

The term causalgia, or as Professor Stopford would prefer it "thermalgia," signifying a combination of heat and pain, is applied to the peculiar group of signs and symptoms—burning pain, hyperæsthesia, wasting and vasomotor disturbances—which may appear after wounds of the peripheral nerves, in some painful amputation stumps, and rarely in association with other irritative lesions of nerves apart from penetrating wounds The most characteristic cases are of traumatic origin, the pain being localized to the territory of the irritated nerve, accompanied by glossy skin, exaggerated by emotion, and relieved by the application of cold water But burning pain is also associated with many conditions, including erythromelalgia, obliterative arteritis, Raynaud's disease, and various forms of neuritis, in all of which a prominent feature is some alteration in the circulation through the painful part

The objective phenomena of causalgia are faithfully reproduced in varying degrees of intensity in all cases of the disorder, and certain of them, such as vasodilatation and trophic affections of the skin, may almost be measured quantitatively, or at least accurately enough to indicate their severity Of much less value, however, is the subjective evidence, for the patient's own estimate of the intensity of his sufferings depends on his mental state and temperament, and does not necessarily indicate the extent of the underlying organic lesion It is often thought that some patients are more sensitive to pain than others, and this, coupled with the fact that a large number tend in time to undergo spontaneous cure, makes causalgia a difficult clinical problem Even when relief follows a certain operation, one cannot help wondering how important the mere psychological effect of the operation may be, and though relief may follow the

bearing a date before the Great War number only twelve, as compared with 145 added since 1915. It was in 1917 that Leriche[9] published the account of the success which had attended his treatment of causalgia by periarterial sympathectomy. He stressed the observation that causalgia occurs most frequently in wounds of the median and sciatic nerves, and as he considered that the explanation lay in the fact that these nerves are accompanied by fair-sized bloodvessels, he suggested that measures which would improve the circulation to the part might therefore be expected to alleviate the pain.

The Clinical Picture.—Causalgia does not appear immediately after the infliction of a wound, but becomes established during its healing, which is frequently, but not invariably, complicated by infection.

Pain.—The pain of causalgia differs in many respects from that of peripheral neuritis. The outstanding feature is its burning character, which is intensified by warmth and dependency. With the limb supported and at rest the patient is conscious of discomfort, which is constant and disturbing, but is not severe. If, however, the affected limb be exercised, allowed to hang down, or to become hot, the burning rapidly increases in severity and may become almost intolerable, requiring many hours of rest and elevation of the limb to afford relief. Any manipulation, or even stroking the skin, will produce the pain, and the patient will protect the extremity by wrapping it up in bandages or cloths which have been soaked in cold water, in the hope of relieving the feeling of burning heat.

In highly sensitive patients paroxysms may be evoked by a fright, an unexpected noise, by anxiety or anything which will excite an emotional reaction. The patient may be in the most peaceful surroundings, even in the depths of the country, when some trivial but unexpected incident, such as a bird suddenly flying out of a neighbouring hedge, will cause him to collapse in a paroxysm of pain.

operation too rapidly to be attributed to coincident natural cure, yet it is sometimes difficult to say just what step in the operation has been effective, and how the improvement is to be explained on physiological grounds

Percivall Pott, in his lectures, referred to the intractable pain which sometimes results from partial division of a nerve, but the first clear account of causalgia was given in 1813 by Alexander Denmark, Surgeon to Haslar Hospital The patient was a young soldier who was wounded at the storming of Badajoz, and a vivid word-picture is drawn of typical median nerve causalgia, associated with ulceration of the palm of the hand, and with an exquisitely tender spot on the forearm, beneath which a small fragment of ball shot was subsequently found

Further contributions to the subject were made by Hamilton of Dublin (1838) and by Paget (1864), but Weir Mitchell's description of this peculiar type of pain occurring in soldiers wounded during the American Civil War must be considered to be the first comprehensive clinical study The monograph on "Gunshot Wounds and other Injuries of Nerves," which he wrote in collaboration with Morehouse and Keen, appeared in 1864, and by his lucid exposition of this peculiar pain following incomplete division of a nerve, Weir Mitchell obtained general recognition for the syndrome for which he coined the term "causalgia" His original description of the clinical aspects cannot be excelled, and the more recent additions to the literature deal entirely with theories put forward to explain the phenomena, or record the results of the numerous forms of treatment which have been employed

Whereas penetrating wounds involving peripheral nerves are comparatively rare in civil life, the wounds of war include a much larger proportion of such cases The first recorded case of causalgia was that of a wounded soldier, Weir Mitchell's cases were collected during the American Civil War, and in a bibliography published recently by Paul Blanchet the items

PLATE XIII

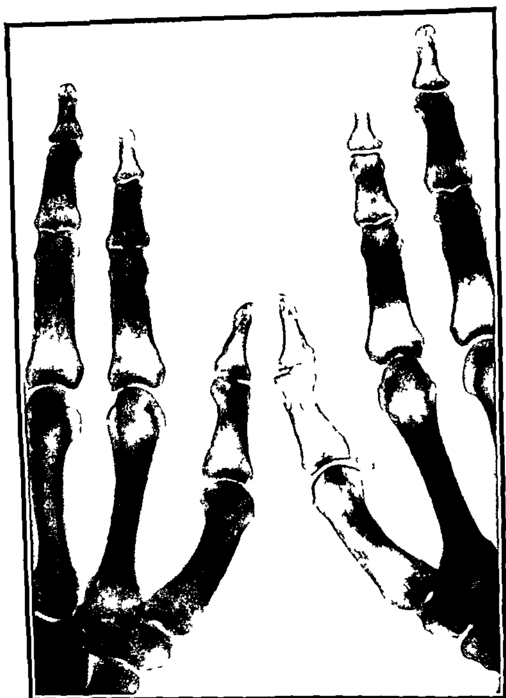


FIG 42 —SKIAGRAM SHOWING RAREFACTION OF THE PHALANGES OF THE THUMB, AND SOME DIMINUTION IN THE DENSITY OF THE PHALANGES OF THE INDEX FINGER IN CAUSALGIA AFFECTING THE OUTER BRANCH OF THE MEDIAN NERVE

On the left side of the skiagram the patient's unaffected hand has been included for comparison

[*To face page* 146

Hyperæsthesia.—The cutaneous area supplied by the affected branch of the nerve shows well-marked hyperæsthesia, which becomes more pronounced if the limb becomes warmer. This hyperæsthetic area may extend beyond the distribution of the affected branch to that of other branches of the same nerve, and in severe cases it may spread beyond these limits, appearing to follow the sensory distribution of spinal segments. A few cases have been recorded in which distant parts of the body, or even its whole surface, seemed hyperexcitable, a stimulus applied to various remote parts producing a reaction accompanied by exacerbation of the local pain.

In cases of average severity a light touch in the causalgic area will be painful, and tapping the surface gives rise to a stab or "shoot" of pain up the limb. Deep sensibility also is increased, and gentle kneading of the muscles will be painful.

Temperature sense is involved, for a moderately low temperature produces an aching sensation, whereas a moderately high one causes the typical burning pain. Immersion of the limb in water which to a normal individual would appear merely cold or hot, as distinct from cool or warm, gives rise to a sensation which is purely painful, and the patient is very careful to avoid anything approaching extremes of temperature because of the intensity of the pain evoked.

Wasting.—Wasting of the tissues is a constant feature in causalgia, and is best seen in the fingers. The skin becomes glossy, thin and hairless. Wasting of the subcutaneous tissue is well shown in the finger-pads, which shrink and leave the nails protruding and curving over their ends. A skiagram will show that the change extends more deeply still, the phalanges becoming gradually decalcified (Fig. 42). It is well known that such decalcification and rarefaction is associated with dilatation of the bloodvessels in the bone.

Vasodilatation.—Under the usual conditions of room and body temperature there is a striking contrast between the cool,

pink skin of the normal digits and the hot, red, shiny skin of the painful ones When the external temperature is low the affected parts are of a mottled red and blue colour, and are colder than normal, but when it rises, or if the whole body is warmed in a bath, or by exercise, the temperature of the painful parts rises abnormally high, the combination of pain, heat and redness suggesting an acute inflammatory reaction, or resembling an extensive chilblain Skin temperature observations show that when the skin is warm pain is most severe, and if it is cooled gradually by immersion in a bath of water at 15° C a point is reached at which pain ceases, and is replaced by aching as the temperature drops still lower

In the most severe cases the disturbance of the circulation in the minute vessels of the skin leads to herpetic eruptions, ulceration and other evidences of malnutrition

All our patients have shown vasodilatation and abnormal warmth of the parts involved, but a smaller "ischæmic" group has been described in which the skin is pale and cold

Sweating—If a cutaneous nerve be completely severed, the skin to which it is distributed becomes anæsthetic and dry In causalgia, however, the partial lesion of the nerve is associated with excessive sweating Even when the extremity is cool the affected skin is covered by fine droplets, but if the body is warmed up this area rapidly becomes drenched with the profuse secretion of sweat

Mental State—To complete the clinical picture it must be stated that the patients seem to possess a peculiar "emotional" temperament, which may be of importance in the establishment of causalgia, but is certainly an important complication which aggravates the symptoms, which may in turn produce profound changes in the mental state of the patient

The Nature of Causalgia—It must be noted that the sensory phenomena of causalgia are made up of two components, for in addition to the local pain and tenderness which occur with any nerve injury, we have to deal with a

spread area of hyperæsthesia by supposing that there is hyperexcitability of sympathetic centres which correspond to the irritated nerve, and that the hyperexcitable state spreads to neighbouring sympathetic centres He went on to trace what he described as the path of the sympathetic reflex underlying causalgia, impulses passing from the wound in the peripheral nerve towards the central sympathetic centres Yet it was Tinel who showed that causalgia may be cured by section of the wounded nerve peripheral to the lesion !

Attention has already been drawn to the fact that, if nerves in amputation stumps be excluded, causalgia follows only those injuries which do not completely divide the affected nerve It may be assumed that stimulation of the supposed afferent sympathetic fibres could take place at the site of injury whether the division were complete or not, and this theory thus fails to explain the clinical phenomena

It has been suggested that pain impulses themselves may travel along sympathetic fibres to reach the spinal cord In repeated examinations of patients upon whom sympathetic ganglionectomy has been performed we have so far failed to detect any loss of pain, touch or deep sensibility in limbs which show complete paralysis of vasomotor, sudomotor and pilomotor nerves

But the greatest difficulty in accepting the idea of sympathetic over-activity lies in the fact that causalgia is characterized by vasodilatation Stimulation of the sympathetic should be associated with vasoconstriction, for even allowing that vasodilator fibres may exist in sympathetic nerves, the vasoconstrictor fibres form such an overwhelming majority that stimulation of a sympathetic nerve will produce vasoconstriction To account for vasodilatation it would be necessary to postulate a reflex inhibition or paralysis of vasoconstriction, but the clinical picture is one of irritation, surely not of paralysis

There is no doubt, however, that the secret lies in the nervous control of the peripheral bloodvessels It has

peculiar variety of pain associated with diffuse hyperæsthesia and characteristic vasomotor phenomena It is our ignorance of the cause of this extra component which makes the treatment of causalgia such a difficult problem

Many theories have been advanced to account for the characteristic syndrome of causalgia The suggestion that it may be due to an ascending neuritis of the injured nerve fails to explain its special features, and though this idea received some support from the work of Dean Lewis and Gatewood,[9] who treated a group of cases successfully by intraneural injection of alcohol above the level of the lesion, the theory became untenable when Tinel[10] showed that causalgia could be relieved by section and suture of the affected nerve distal to the lesion

It may be recalled that sufferers from Raynaud's disease complain of pain which is an ache during the cyanotic stage of an attack while the fingers are cold, but becomes an intense burning pain as the attack is passing off and the fingers are becoming warm In this respect the pain of causalgia resembles that of Raynaud's disease, a malady the cause of which is to be found in the peripheral bloodvessels

Seeing that hyperæsthesia in causalgia seems to vary with the temperature of the part and the degree of vasodilatation present, it is tempting to assume that we are dealing with a hyperæmic and *therefore* hyperæsthetic area The close similarity between the hyperæmia and hyperæsthesia of acute inflammation and of causalgia is obvious, and the explanation of the hyperæsthesia may be the same in both cases

French clinicians have concentrated upon the reactions which they ascribe to hypersensitiveness of the sympathetic system, epitomized in Professor Froment's dictum that causalgia is " the cry of the sympathetic " In their eagerness to find a basis for their argument they postulate the existence of tracts and centres unknown to anatomists and physiologists For example, Tinel, in " A Contribution to the Study of the Sympathetic Origin of Causalgia " (1917), explained the wide-

the arterioles and capillaries is due to the local liberation of "H"-substance, a chemical body whose action upon these "minute vessels" is the same as that of acetylcholine and histamine He included the formation of herpetic vesicles and trophic changes in the skin among the effects of the peripheral release of "H"-substance, and he gave it as his opinion that the manifestations of irritative nerve lesions of the causalgia type would find their explanation upon the same lines

Seeing that stimulation of the sympathetic produces vasoconstriction and that the predominant vascular change in causalgia is vasodilatation, it is not clear at first why sympathectomy should be beneficial in causalgia But it must be

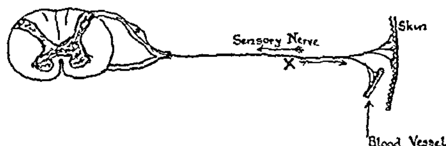


FIG 43—IRRITATIVE LESION AT X PRODUCES VASODILATATION BY ANTIDROMIC IMPULSES PASSING ALONG THE SENSORY NERVE TO THE BLOODVESSEL (AFTER BAINBRIDGE AND MENZIES)

remembered that the constrictor effect of the sympathetic is noted in the small arteries, and it has already been explained that though paralysis of the sympathetic gives rise to dilatation of the arteries, it also produces constriction of the minute vessels by washing away "H"-substance (*vide* p 80) In causalgia we must assume that we are dealing with a sensory nerve stimulated by intraneural fibrosis resulting from injury Vasodilatation of the minute vessels, wasting, glossy skin and herpetic eruptions are all to be explained by the release of "H"-substance by antidromic impulses Sympathectomy leads to the removal of this "H"-substance, and thus abolishes the peripheral manifestations of causalgia

Weir Mitchell, realizing that there was more in causalgia

been shown that there is a preponderating association of causalgia with those nerves which convey most of the vasomotor fibres to the periphery—that is to say, the nerves which have the largest area of cutaneous distribution Furthermore, the measures which are successful in treatment are those which prevent overfilling of the minute vessels Not only does elevation of the part relieve the pain, but it is of interest and importance to note that Foix[11] has reported cases in which pain was relieved temporarily by compression of the radial or posterior tibial artery, and was completely abolished by ligation of these vessels

But it is a mistake to assume that the sympathetic alone is responsible for vasomotor control Thirty years ago Bayliss demonstrated that after removal of the spinal cord, leaving the posterior root ganglia intact, stimulation of the remaining fibres caused vasodilatation He concluded that the fibres mediating this response were identical with ordinary sensory fibres, and that impulses travelled along them towards the periphery (antidromic impulses) Bayliss's comment runs "Owing to the fact that nerve fibres conduct in both directions, it will be seen that if one branch of a nerve fibre which has divided is put into excitation by some means, the impulses will spread over all the other branches of the same fibre" A sensory nerve has a vasodilator branch to an arteriole, and when the nerve is stimulated the antidromic impulse thus produced travels along this branch and gives rise to dilatation of the small vessel (Fig 43) Pain, heat, swelling and redness of inflammation are thus accounted for

In 1927 Lewis[12] published some very important work which was designed to investigate in greater detail the action of these antidromic impulses Starting with the knowledge that if the peripheral end of a cut sensory nerve be stimulated the affected part of the skin flushes, thus showing that antidromic (vasodilator) impulses overcome the vasoconstrictor impulses passing by the sympathetic vasomotor fibres, he brought forward experimental proof that vasodilatation of

this burning pain, which is peculiar to causalgia, is relieved by sympathectomy, it will also be necessary in most instances to free the nerve from scar tissue or to resect a sensitive end bulb in order to abolish the sensory phenomena which are common to all nerve injuries This is of secondary importance, and past experience shows how slight is the relief afforded by this step alone in the treatment of causalgia

Treatment—Mild cases and even some of the severe cases of causalgia tend to undergo spontaneous recovery, but the process is slow and uncertain Various forms of treatment have been tried in the hope of curing the condition, or at least of shortening its course, but their number and variety cast grave doubt upon the efficacy of any particular method

Weir Mitchell advocated continuous blistering, and reference has been made above to the operations upon the injured nerve both proximal and distal to the lesion, and to ligation of the vessels supplying the part involved The view generally held at the end of the war may be gathered from the Report of the Committee upon Injuries of the Nervous System, published by the Medical Research Council in 1920 The Report advised that if the patient were of a stable type and could bear pain well, operative measures would be unnecessary If, however, he were unduly sensitive or obviously neurotic, radical treatment should be adopted early—either injection of the nerve with alcohol above the site of the lesion, or division and suture of the nerve In slight cases psychotherapeutic treatment would be found to be of great value in preventing the development of a serious neurosis

Pain is likely to be abolished by section or alcohol injection of the nerve, but the great disadvantage of this procedure is that functional recovery will take many months, and may never be perfect In the meantime, however, Leriche[8] had recorded a number of cases treated successfully by periarterial sympathectomy This operation, combined as a rule with local neurolysis, is often sufficient to give the patient

than merely a severe peripheral neuritis, believed that injury of the nerve produced alterations in the circulation and nutrition in its area of distribution which were painful, and he considered it essentially "a painful disease of the nutrient nerves" It is difficult to fit this idea into the modern conception of the physiology of the nervous system, but it is significant that Weir Mitchell looked for the source of the pain, not in the nerve itself, but in the tissues to which it is distributed

The bloodvessels are well supplied with afferent nerve fibres, and there is good reason to suppose that pain can be produced by stimulation of these nerves The adequate stimulus may be chemical, perhaps "H"-substance or other metabolites, but there is evidence to support the view that they are sensitive, as are the viscera, to tension on their walls The pain produced by a tourniquet applied tightly enough to occlude veins, but not arteries, is a well-known phenomenon, and anyone who has started an intravenous injection before the constricting band has been relaxed will have observed the pain produced by distending the vessel

Those who advocate the theory of chemical stimulation assume the accumulation of tissue waste products which are imperfectly oxidized, and the suggestion is that mere oxygen lack may lead to stimulation of nerve endings Yet acrocyanosis is painless, though the cyanosis indicates excess of reduced hæmoglobin, whereas in erythromelalgia, with excess of oxygen in the peripheral blood, there is extreme pain In acrocyanosis, however, the arterioles are constricted by cold and there is no vascular overfilling

The pain of causalgia may be alleviated by arterial compression, or by cold, which constricts the small arteries and prevents overfilling and overdistension of the minute vessels, yet both these procedures involve a diminution in the oxygen supply to the periphery It therefore seems possible that the radiating pain of causalgia may be due to increased tension within the minute vessels of the affected part Though

tation of the thumb was performed through the proximal phalanx, but severe causalgia developed which involved the stump, the thenar eminence and the index finger

In September, 1931, periarterial neurectomy of the right brachial artery resulted in disappearance of the hyperæsthesia from the index finger, but the stump and thenar eminence were still abnormally sensitive After this initial improvement the condition of the hand became worse than it was before the operation, and at the beginning of November, 1931, the skin of the stump, thenar eminence and index finger was exquisitely tender, red, hot and bathed in sweat There was a group of herpetic vesicles on the pad of the index finger (Fig 29, p 81)

On November 16, 1931, cervicothoracic ganglionectomy was carried out on the right side Within forty-eight hours the herpes had completely dried up, and as the skin became pale, hyperæsthesia disappeared entirely A tender spot due to an "end bulb" remained in the amputation scar, and since its removal with the base of the proximal phalanx, in February, 1932, the patient has been quite free from pain and has been able to return to work after a period of unemployment which lasted for well over two years

Similar experiences have been recorded by Leriche, Petit-Dutaillis,[13] Spurling,[14] White,[15] and Stammers [16] Certain of these observers have hinted that there was evidence of disease in the excised tissues, but our experience leads us to the conclusion that the good results of sympathectomy are to be attributed, not to eradication of some fault in the sympathetic nerves themselves, but to the effect of the operation upon the bloodvessels

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relief, and even if unsuccessful is unattended by any disability It is therefore justifiable to perform the periarterial operation on the ground that the best surgical procedure is one which can achieve its object with the minimum of interference with the rest of the body, but it must be remembered that this operation is an imperfect form of sympathectomy, and something more radical may be required should it fail It often happens that patients with causalgia are psychologically unfitted for such a therapeutic experiment, and one cannot afford to run the risk of an initial failure which would undermine their confidence in any future operation Under such circumstances it is wiser to denervate the affected limb by ganglionectomy at the outset, in spite of the other effects of sympathetic paralysis, which may be for a time a source of complaint

We have had the opportunity of performing periarterial neurectomy for causalgia on five patients, three of whom were relieved of their symptoms and were able to return to work, in spite of the fact that before operation there had been prolonged periods of disability, and various other methods of treatment had proved unavailing In these patients the circulation in the affected digits and their nutrition was markedly improved as a result of the operation, and thermal stimuli, which had previously been painful, no longer gave rise to discomfort The last of these successful operations was performed eighteen months ago, and no relapse has occurred

The other two patients, however, were improved only for *a few weeks, but subsequent ganglionectomy has abolished* the signs and symptoms of vascular disorder in the affected digits One of the cases is particularly interesting in this respect, and will be described in greater detail

A paper-maker, twenty-nine years of age, lost the top of his right thumb in a machine accident in December, 1929 The wound suppurated for three weeks and the stump remained tender after it had healed In March, 1930, ampu-

CONCLUSION

PORTIONS of the sympathetic nervous system have been removed for the treatment of many conditions which have not been mentioned in the preceding pages Sympathetic ganglionectomy was first performed by Alexander of Liverpool for epilepsy, and the operation has been carried out by many surgeons, with variable results, in the treatment of exophthalmic goitre Among the many other disorders which have been treated by sympathectomy, retinitis pigmentosa and bronchial asthma may be mentioned as being perhaps the most important Though there are numerous references to these diseases in the literature, we have deliberately excluded them, and have confined our account to those conditions of which we have had personal experience

Extensive bibliographies of the sympathetic nervous system have been published already, and the short list of references which appears at the end of every chapter in this book includes only the papers which have been of value to us in establishing the theoretical basis, or in devising the practical details of the operations we have described It will be apparent that we have made little acknowledgment of our debt to the renowned physiologists whose discoveries laid the foundation of our knowledge, and that no adequate tribute has been paid to the Continental surgeons whose pioneer work during the past thirty years has cleared the ground for the more recent developments in the surgery of the sympathetic system Our excuse must be that we have devoted our attention almost entirely to current literature to try to discover the end results of, and thus the indications for, sympathectomy

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the sympathetic system fall into a group which is characterized by a certain "temperament" The expression wafts us back to the Island of Cos, where 300 years before Christ we might have listened to Hippocrates expounding his ideas of humoral pathology, or at least as far back as the second century of our present era, when Galen was recording ingenious theories in his books on the temperaments! Yet, if we knew what this attribute of temperament signifies, and its relationship to inherited traits and characteristics which seem to play such a prominent part in certain of these disorders, we might be considerably nearer an understanding of the fundamental pathology of the sympathetic system

This confession of our ignorance is to be regarded not as an excuse for despondency, but as a spur to renewed endeavour, for it must be realized that until more is known about the pathology of the sympathetic system, the place of surgery in the treatment of its disorders cannot be firmly established

It may also be remarked that no account has been given of the pathology of the sympathetic system. Apart from tumours arising in its ganglia, which are of minor importance, there is no pathology at the present time. Raynaud believed that the malady he described was due to some form of disease affecting the sympathetic system, but this conception now has to be abandoned. The various conditions which are treated by operating upon the sympathetic nerves and ganglia are due to abnormalities of the organs themselves, or else their cause is at present unknown; and careful histological examination of the ganglia and nerve trunks which we have removed has failed to reveal any structural abnormality. What surgery attempts is not the removal of a diseased structure, but the interruption of certain impulses passing along apparently normal pathways.

It may be that disease sometimes exists in the antagonists of the sympathetic, and that diminution of their activity creates a relative sympathetic over-action, which may be reduced by cutting off sympathetic impulses. But in other cases we seem to be dealing with an actual excess of sympathetic activity, and the question arises whether such a condition can reasonably be postulated.

Penfield's case of hypothalamic tumour suggests that such a state may be produced by stimulation of hypothalamic centres, but obviously tumour formation must be very uncommon as its cause. What else could stimulate the hypothalamus? Some might look for the answer in the pituitary body, which is known to exert an important influence upon the functions of the hypothalamus. Others, still seeking among the endocrine glands for the fundamental error, would be more inclined to regard the suprarenal gland as offering a more fruitful field for research.

Finally, it might be argued that the fault lies in the mental condition of the patient, and that the cerebral cortical control of the hypothalamus is imperfect. This conception may underlie the opinion that individuals subject to disorders of

INDEX

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